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THE EFFECT OF ENVIRONMENT ON THE COMPRESSIVE STRENGTHS OF LAMIN--ETC(U)

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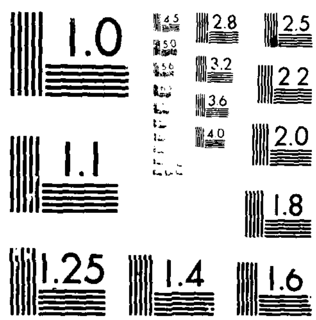
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AFML-TR-79-4179

LEVEL II

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EFFECT OF ENVIRONMENT OF THE COMPRESSIVE STRENGTHS OF LAMINATED EPOXY MATRIX COMPOSITES

LOCKHEED-CALIFORNIA COMPANY
BURBANK, CALIFORNIA

DECEMBER 1979

TECHNICAL REPORT AFML-TR-79-4179
Final Report for period 15 August 1977 to 28 September 1979

Approved for public release; distribution unlimited.

AIR FORCE MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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J. M. Whitney

J. M. WHITNEY, Project Engineer
Mechanics & Surface Interactions Br.
Nonmetallic Materials Division

S. W. Tsai

S. W. TSAI, Chief
Mechanics & Surface Interactions Br.
Nonmetallic Materials Division

FOR THE COMMANDER

J M Kelble

J. M. KELBLE, Chief
Nonmetallic Materials Division

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The program was designed to assess the effects of temperature and absorbed moisture on the static compression behavior of epoxy matrix composites under loading conditions wherein the dominant failure modes are those which occur in structural applications. Compression test fixtures providing varying degrees of geometrical constraint were employed in order to conduct a complete series of column tests ranging from perfectly elastic to fully restrained. Two graphite/epoxy materials were evaluated, T300/5208 and

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AS/3501-5A. Both longitudinal and transverse orientations of three specimen types, a 0-degree unidirectional, a quasi-isotropic and a 67%-0-degree laminate were evaluated at four temperatures, -54°C (-65°F), 22°C (72°F), 93°C (200°F) and 135°C (275°F) after exposure to one of two environmental conditions: dry, (22°C (72°F) and 40% R.H.) and wet (82°C (180°F) and 90% R.H.). Both materials were chacterized under static-tension and shear loading and Tg, thermal expansion and moisture distributions were determined. Analytical procedures for predicting the column buckling behavior under various conditions were developed.

Elastic buckling of the laminates investigated were relatively unaffected by moisture and temperature. The inelastic buckling curve revealed a drop due to moisture and temperature which was dependent upon material and laminate type.

FOREWORD

The investigation of the compression and column buckling behavior of laminates reported herein was performed by the Lockheed-California Company, Burbank, Ca, a division of Lockheed Corporation, under Air Force Contract F33615-77-C-5140. The Air Force Project Engineer directing the program was Dr. J. M. Whitney (AFML/MBM) of the Mechanics and Surface Interactions Branch, Non-metallic Materials Division, Air Force Materials Laboratory at Wright-Patterson AFB, Ohio. The program was conducted by the Structures and Materials Department of the Lockheed-California Company, with K. N. Lauraitis as Principal Investigator, assisted by P. E. Sandorff in the area of analysis. The work reported herein was performed during the period of August 1977 through September 1979.

The support and contributions of Mr. D. E. Pettit, Group Engineer, Fatigue and Fracture Mechanics Laboratory; Dr. J. T. Ryder of the same laboratory, Mr. Y. A. Tajima and R. C. Young of the Materials Laboratory, Mr. L. D. Fogg of the Structural Methods Group and especially the considerable contributions in data analysis of Dr. M. Feng are gratefully acknowledged by the authors.

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1. TECHNICAL BACKGROUND

1.1 Problem Definition

Aircraft structures of composite laminates have features similar in many respects to metal structures. Parameters comparing material properties to the density of loading differ, but not so much as to markedly change or reduce the modes of failure which must be considered in the design of structures for compresssion loads, namely, column instability, skin buckling, stiffener element buckling, the interaction of skins and stiffeners, crippling and/or compression rupture.

Material yielding, which effectively establishes the maximum compression that can be carried in metal structure, is replaced in composite materials by a "compression ultimate" mode which involves matrix failure, fiber separation, and/or ply delamination. Materials tests indicate essentially elastic (although slightly non-linear) deformation characteristics up to the point of catastrophic failure. Designers, therefore, usually consider only two modes in the determination of allowable compressive loads: (1) elastic instability of the laminate as a unit, a value related to the geometry of the system, and (2) compression ultimate, a "cut-off" or maximum value assumed to be independent of geometry.

Materials properties tests are therefore usually directed at determining: (1) the stress-strain properties, in order to evaluate the elastic parameters, and (2) the compression ultimate strength.

However, test engineers familiar with the methods available for conducting the compression ultimate test recognize that the value so determined is not independent of geometry [1]. Specimens used in methods such as the

Celanese [2], IITRI [3], tubular compression [4], side-supported [5], and the sandwich beam [1] differ widely in configuration; they are provided with different types and degrees of restraint to avoid general instability, and they show different sensitivities to variations in fabrication and test setup. Mode of failure, which is a key factor in establishing validity in tests of metals, is of little help in assessing compression ultimate tests of composite laminates because of the immensely complex nature of the typical failure, the variations in mode which occur with layup, and the high probability that the primary mode is obscured by secondary effects. Selection of the "correct" method of compression testing, therefore, can be strongly influenced by considerations such as which provides the highest strength, or which gives the least scatter, or which can be done for the lowest cost, when the proper criterion would be the accuracy with which the performance in aircraft structure is simulated.

Simulation of the behavior of structural elements introduces a variety and a range of geometrical constraints. The most stable elements, by virtue of their massive section, may approach "block compression" strength - a compression ultimate, which depends only upon local material properties and is not influenced by overall geometry or external constraint.

Conventional test methods (as referenced above) utilize thin sections and should not be expected to provide data on block compression strength. Moreover, the majority of aircraft structural elements derive their stability under compression as a result of high curvature or intersecting thin sections, as found in so called "stiffener shapes", or from the elastic foundation support provided by honeycomb substructure. These sections in turn provide support and constraint to less stable flat sections and skin panels. The design of non-buckling structure requires ability to predict the performance of thin sections restrained in various ways and degrees by more stable elements. The design of buckling structure involves, in addition, prediction of the behavior of stable elements under the destabilizing forces and moments introduced by the adjacent buckled panels. Of great interest, therefore, is the nature of instability failures which occur at stresses less than block

compression strength, governed by the combination of material properties, geometry, and external constraints.

1.2 The Column Compression Test

The column compression test is used here as a means of investigating the interaction of material characteristics and geometrical factors over the complete range of failure stresses of interest in design. Test results are not expected to be directly applicable, since there are very few uses in practical structures for a flat laminate plate unsupported at the edges. However, column buckling is closely related to plate buckling, and stiffener crippling only one analytical step removed. With metallic materials, characteristics identified in the simplest of stability tests can be applied through parametric relations to more complex instability problems. Similar generalization may be expected to apply for composite laminates.

The test employs a simple 25 x 150 mm (1 x 6-inch) specimen of flat laminate for all variations in test geometry. Column support against transverse buckling is provided at regular intervals by fixtures positioned on either side of the specimen. The fixtures make line contact with the specimen surface at each support station and thus provide pinned-end conditions. A selection of fixtures with different spacings between the pin supports provides a number of different column test lengths, ranging from long columns which buckle elastically, to relatively short columns, which fail catastrophically.

To provide maximum stabilizing support and develop stresses which represent a zero column length condition, the "compression ultimate", smooth, flat platens are used in place of the pin supports. These are positioned closely to the surfaces of the laminate, although not in forceful contact, since some clearance, estimated at less than 0.025-mm (0.001-inch) is necessary to avoid frictional restraint. The specimen column buckling is thus constrained to a very small wavelength, placing the column instability stress above the critical value for some other mode, such as ply delamination and

instability, or splintering, or shear instability-crushing. Data obtained with this test arrangement are therefore quite similar to those obtained with the more conventional methods of References 1 to 5.

1.3 Compression Testing Procedure

The method of testing composites in compression used in this investigation employed a single specimen design, and test fixtures providing varying degrees of geometrical constraint, in order to conduct a complete series of column tests ranging from perfectly elastic to fully restrained. The specimen was 25.4 mm (1.0 inch) wide and 266.7 mm (10.5 inches) long with 152.4 mm (6.0 inches) test section and tabbed ends. The fixtures permitted testing of the specimen either with pin supports placed at various column lengths, or between smooth platens which prevented buckling entirely.

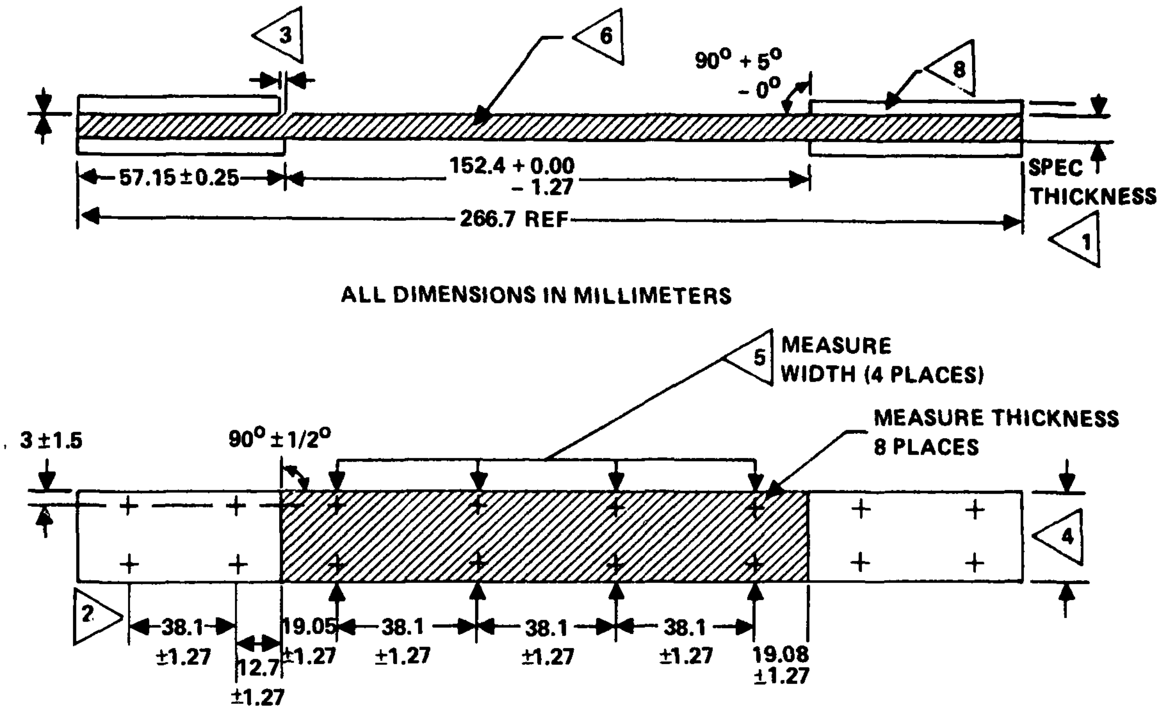
1.3.1 Specimen Design

Details of the specimen used for this test procedure are given in Figure 1. Important features of this configuration are identified as follows:

- Length of the specimen is sufficient to permit testing not only under fully-restrained conditions to obtain a "compressive strength", but also under the complete range of column buckling lengths extending into the elastic "Euler" range, for laminates of practical designs and thicknesses.

- Besides having significance for the conduct of column tests, adequate specimen length is important in composite specimens in order to obtain uniform stress conditions within the test section. Load introduced through the tabs must be transferred to the central plies by shear; the low shear modulus results in appreciable shear lag within the tabbed area, and the resultant relative displacement of surface and centerline fibers must be accommodated within the specimen test length.

- Longer test specimens accommodate more easily to small test misalignment and eccentricity. The 152.4 mm (6.0 inches) gage length selected here is considered important in minimizing stress variations which may be introduced by practical limitations in fabrication tolerances and test installation, and thus in reducing test scatter.



9 SPECIMENS TO BE FLAT OVER THE ENTIRE 267-mm (10.5-in.) LENGTH WITHIN 0.25-mm (0.01-in.)

8 TAB EDGES TO BE PARALLEL TO SIDES OF SPECIMEN WITHIN 0.025-mm (0.001-in.) OVERHANG NOT TO EXCEED 3.8-mm (0.15 in.).

7 THE TAB AND SPECIMEN BONDING SURFACES TO BE THOROUGHLY SOLVENT CLEANED USING METHYL-ETHYL-KETONE PRIOR TO BONDING. A 177°C (350°F) CURING ADHESIVE TO BE USED AND MUST COVER ENTIRE SURFACE UNIFORMLY.

6 SPECIMENS TO BE CUT DRY. MACHINED SURFACES TO BE RMS 50 OR BETTER. NO EDGE DAMAGE OR FIBER SEPARATION SHOULD BE VISIBLE UNDER 10X MAGNIFICATION.

5 MEASURE SPECIMEN WIDTH 4 PLACES. WIDTH MUST NOT VARY BY MORE THAN 0.102-mm (0.004-in.)

4 SPECIMEN WIDTH TO BE 25.4 $^{+0.00}_{-0.50}$ mm (1.00 $^{+0.00}_{-0.02}$ in.).

3 MISMATCH OF TABS FROM SIDE TO SIDE NOT TO EXCEED 0.25-mm (0.01-in.)

2 TABS TO BE CUT FROM AN 8 PLY LAMINATE FABRICATED FROM PREPREG OF 1581 GLASS FABRIC IN A 177°C (350°F) CURING EPOXY. TAB PLUS ADHESIVE THICKNESS MUST NOT VARY SIDE TO SIDE OR END TO END BY MORE THAN 0.25-mm (0.01 in.) AS MEASURED 8 PLACES.

1 SPECIMEN THICKNESS TO BE WITHIN ±0.08-mm (±0.003-in.) OF THE AVERAGE OF 8 THICKNESS MEASUREMENTS.

Figure 1. - Composite compression test specimen.

- Specimen size is sufficient to provide a good probability of including point to point variations in material and layup properties. Size effects will depend on the size and distribution density of weak spots of flaws; as the volume under test is increased, size effects and test scatter are reduced, as are the number of tests required to achieve a given statistical confidence level.

- Variations in test results due to the discontinuity at the specimen edge will, in general, diminish as width is increased. The selected 25.4 mm (1.0 inch) width is typically the minimum width used for tension tests of symmetric angle-ply laminates.

- Dimensions are convenient for fabrication and machining; tolerances required to obtain the necessary precision in test results are achievable without extraordinary measures.

- Tab details for protecting the specimen while gripping and introducing test load have demonstrated effectiveness and practicality.

- The same geometry can also be used for static tension tests and for tension-tension or tension-compression fatigue tests.

1.3.2 Description of Test Procedure

A complete related set of test fixtures was developed at Lockheed which permits compression testing of the composite laminate specimens described above under controlled conditions in either the fully-restrained mode, or under column compression at six different pin-end lengths. The specimen-supporting fixtures were designed for use with commercially available MTS hydraulically-actuated grips, which were installed in a standard universal test machine.

A close fitting shell surrounds each grip providing a mount for transverse adjustment screws that prevent destabilizing motion of the platens and specimen (described in detail below). The grips are rigidly mounted to the machine base and test head, precise alignment having first been achieved with the aid of spherically surfaced seats. A specimen positioning device assures location of the specimen on the load axis of the grips to within about 0.13 mm (0.005 inch).

The fixture used to provide specimen support for testing to "compression ultimate" stress is shown disassembled in Figure 2. The fixture consists of two rigid guides or platens like those used by Ryder and Black [5] and similar in gross form to those of ASTM 694 [6] (Federal Test Standard 406) on the inner surfaces of which are located a set of extendable auxiliary platens which provide support over the full length of the test specimen. The auxiliary platens have a tapered overlap in the width dimension so that no critical length of the specimen is left unsupported. Access holes are provided for extensometer points of 50.8 mm (2.0 inches) gage length, or for electrical strain gages of 1.588 mm (0.0625 inch) length.

The platens are shown assembled to a specimen which is installed in the grips in Figure 3. The four assembly screws are brought finger-tight, providing light pressure between the platens and the specimen. Under these conditions, only a few pounds force is required to cause slippage of the entire platen assembly on the specimen. Exploratory tests have been conducted with the assembly screws tightened with a torque of as much as 1.13 N m (10.0 in.-lbs), without producing distinctive variation in the test results. The installation is completed by bringing the large transverse retraining screws into light contact with the external platens.

Figure 4 shows the installation of the extensometer used with this equipment. This instrument, which is of Lockheed-California Company design [7], utilizes a microformer sensor to provide a strain signal for conventional load-strain recording apparatus. An acrylic enclosure usually surrounds the equipment during testing; this enclosure is shown in position in Figure 5. For elevated temperature tests, the internal space is supplied with heated air; liquid nitrogen is used to provide low temperature gas for tests to -54°C (-65°F). For test temperatures above 82°C (180°F) a metal enclosure is ulilized. This system provides specimen temperatures which are uniform throughout and controlled to ±1°C (±2°F).

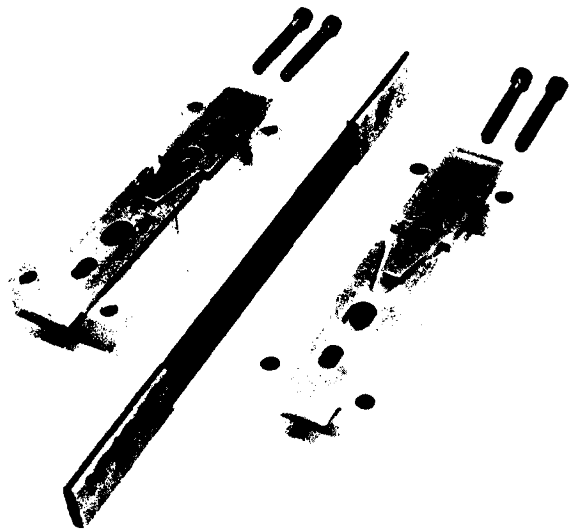


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Figure 2. - "Full-fixity" apparatus, showing auxiliary platens.

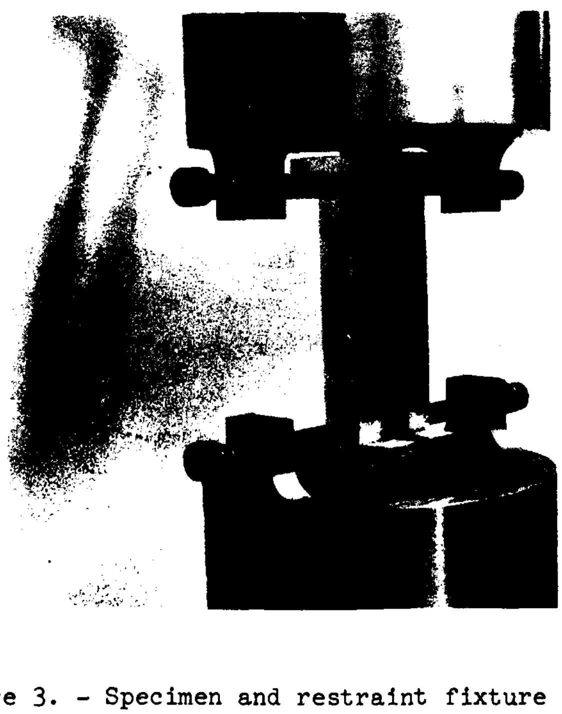

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Figure 3. - Specimen and restraint fixture installed in grips.

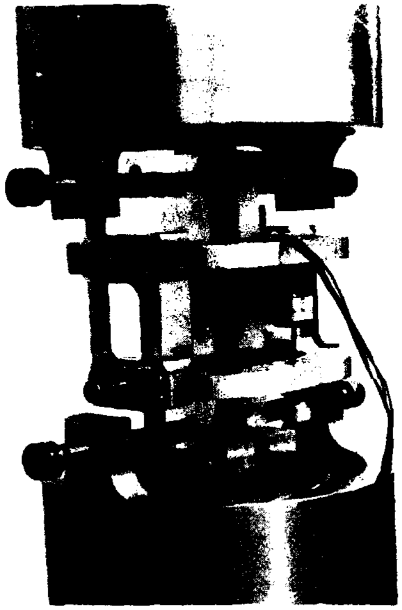

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Figure 4. - Installation of Lockheed extensometer.

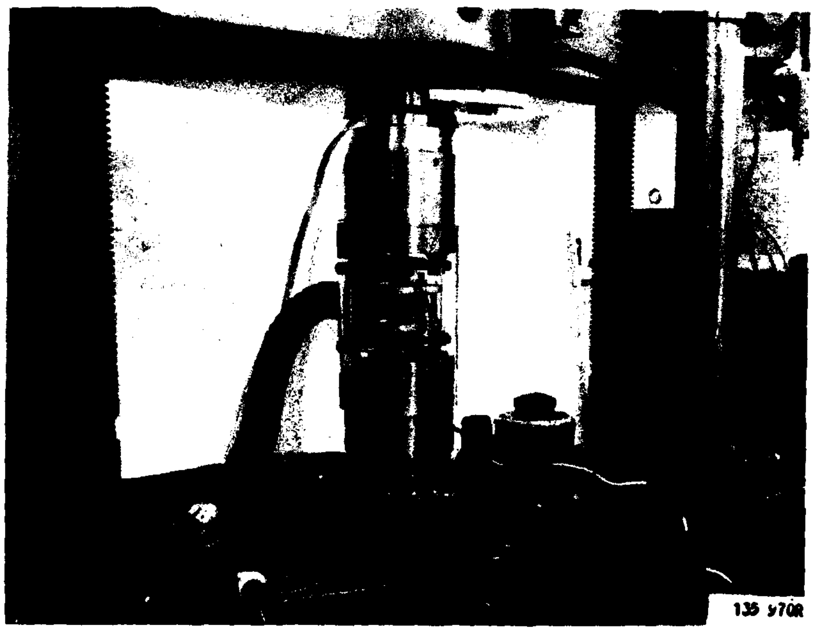

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Figure 5. - Overall view of composite compression test apparatus, with acrylic enclosure and warm air supply.

Pin-end column test conditions are provided using the same general test arrangement as described above, but with the smooth auxiliary platens of the specimen support fixture replaced with pin-locating platens as shown in Figure 6. Six different sets of platens were manufactured, illustrated in Figure 7. These provide pin-end test lengths of 40.79, 32.4, 26.87, 20.04, 14.50, and 8.81 mm (1.606, 1.276, 1.058, 0.789, 0.571, and 0.347 inches) obtained with 3, 4, 5, 7, 10, and 17 bays respectively, for the specimen design previously described.

The tabbed ends of the specimen are gripped in the usual manner, providing a high degree of end fixity in the end bays. To assess this fixity condition, representative specimens were installed in one grip only and loaded cantilever fashion. Deflection data indicated that the fixity could be approximated by assuming fully clamped conditions within the grip at a distance 2.54 mm (0.10 inch) beyond the edge of the end tab. Thus, the overall multi-bay column length between fully-fixed ends was taken as 157.5 mm (6.20 inches) and the end bays have a length 1.406 times that of the inner pin-supported bays, resulting in the same equivalent pin-end length for all bays[8].

1.3.3 Experimental Verification of Test Method

Experimental verification of the testing procedure was obtained using coupons of aluminum alloy. To confirm the behavior of the stress-strain relationship using the auxiliary platens, coupons of 7075-T6 bare aluminum were tested. The results of one such test are presented in Figure 8. A completely regular stress-strain curve is seen, to the limits of the test.

To confirm the performance of the column test apparatus, a series of tests were conducted at various pin-end lengths on a specimen of 0.838 mm (0.033 inch) thick 2024-T3 bare aluminum alloy. Autographically recorded load-deflection curves obtained from test head motion are presented in Figure 9; these provided values of the critical load, which, for the shortest test length, proved to be sudden and to involve permanent deformation. The load-deflection data also permitted experimental determination of the modulus

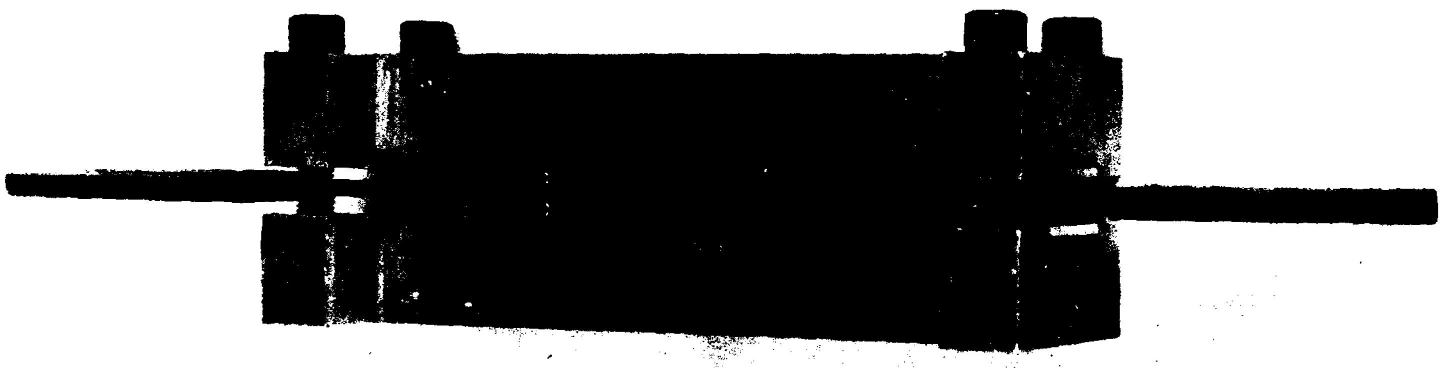

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Figure 6. - Composite specimen column test fixture.

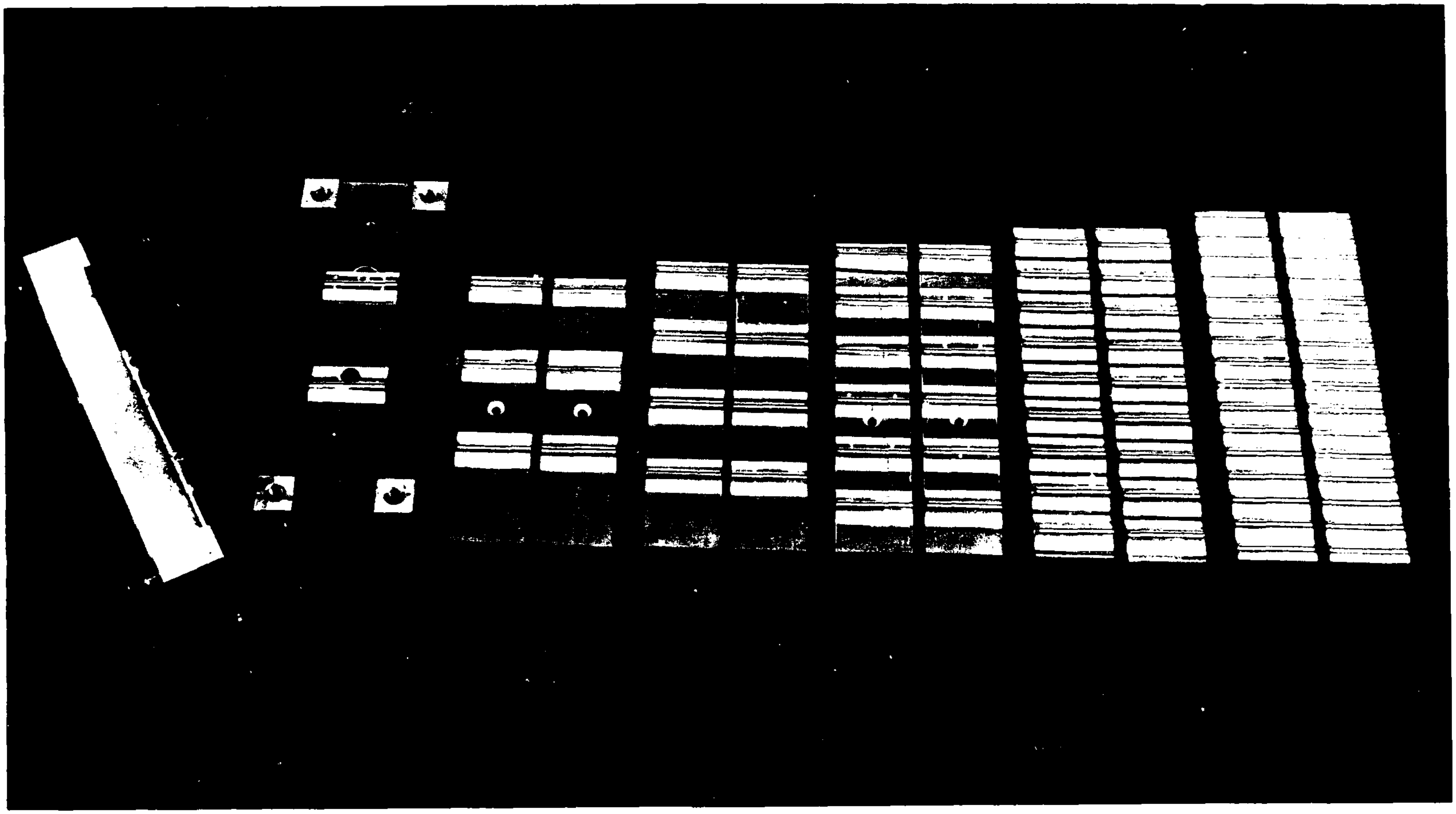

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Figure 7. - Column test platens of various pin-end lengths.

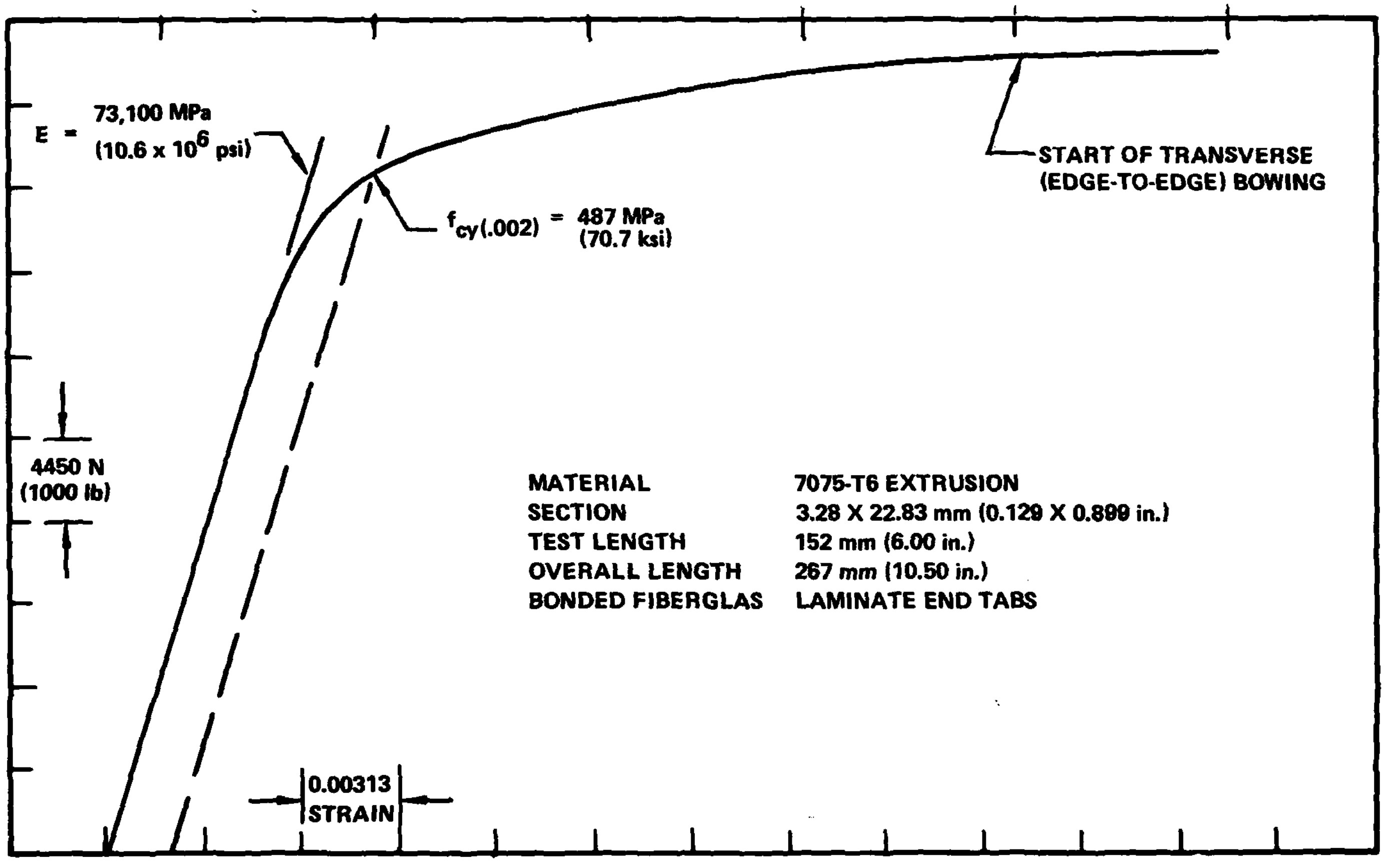


Figure 8. - Autographically recorded extensometer data obtained during compression test of Al alloy coupon in full fixity apparatus.

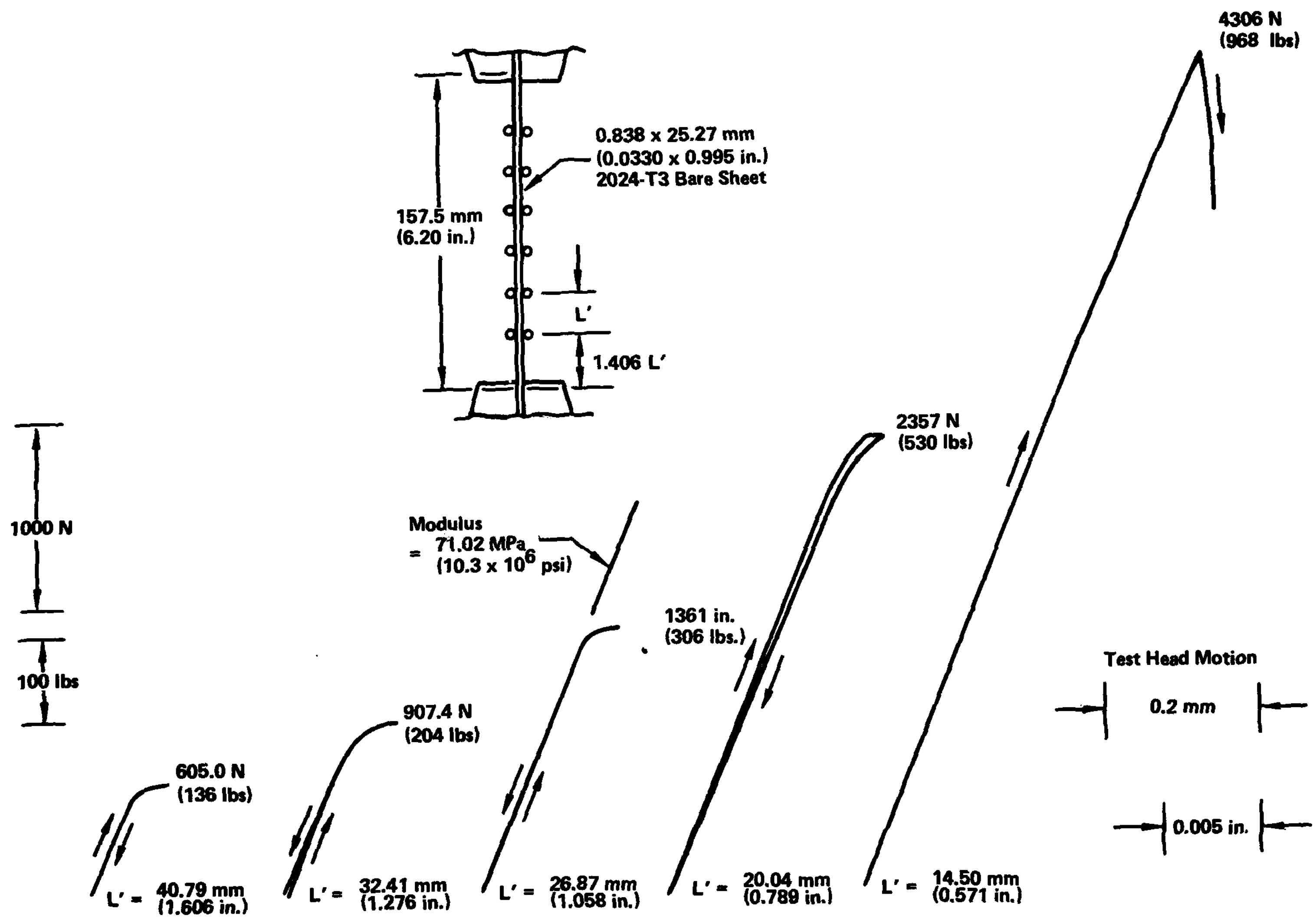


Figure 9. - Load-deflection data obtained in tests of aluminum alloy sheet material in column test apparatus.

of elasticity, which was used in constructing the comparison of test data with the Euler relation in Figure 10. The regularity and consistency of these data provide confidence in the method of column testing this type of specimen.

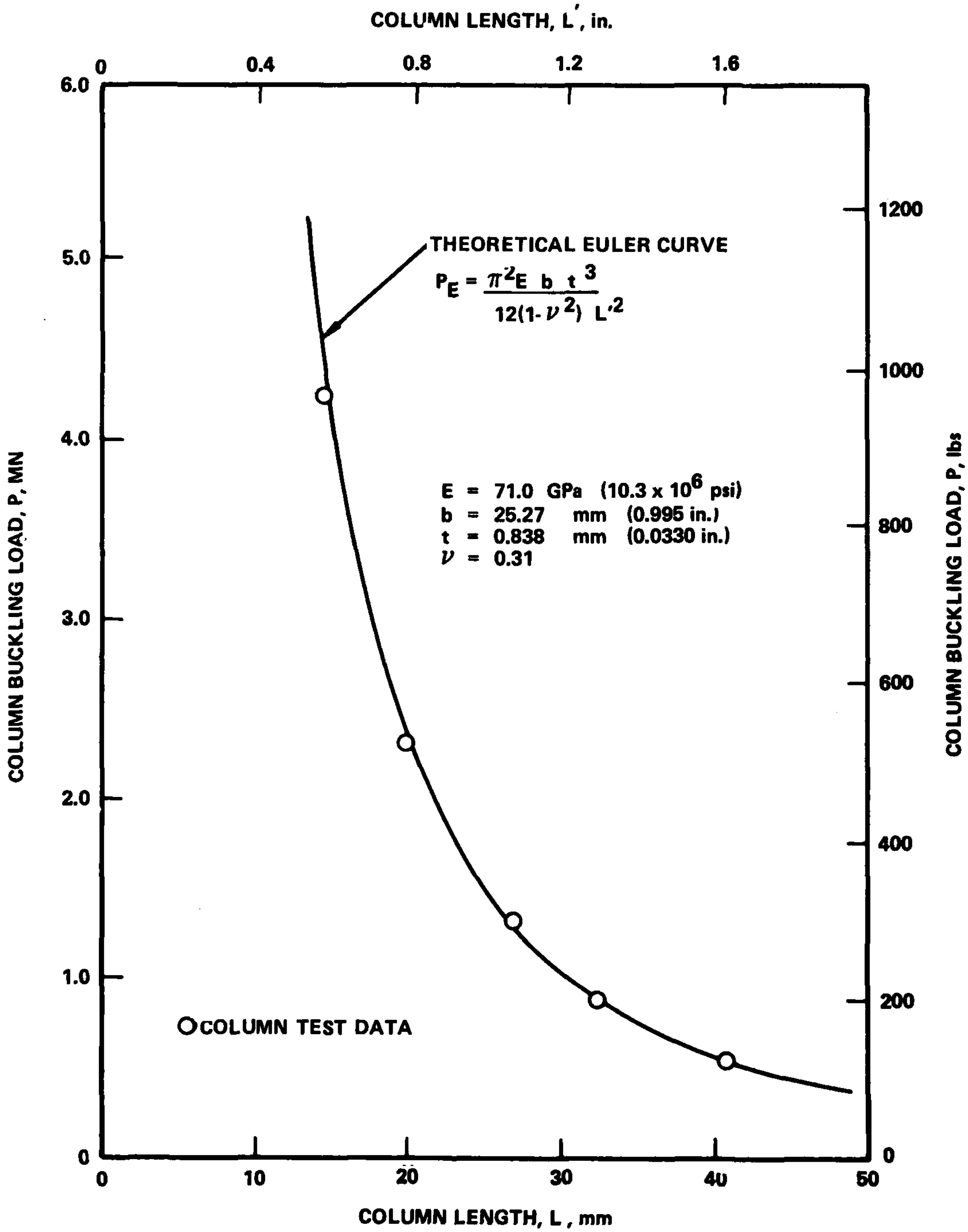


Figure 10. - Test data obtained with column test fixture on 2024-T3 aluminum alloy specimen compared with euler relation.

2. PROGRAM OVERVIEW

2.1 Material Selection

Two materials, Narmco T300/5208 and Hercules AS/3501-5A, were selected for evaluation in this program based upon the following considerations:

- Buckling behavior may be influenced by the fiber form. AS fiber is customarily available as a 10,000 filament tow. Because of its form, this untwisted fiber does not nest well and results in prepreg having greater bulk and requiring higher resin content in both the prepreg and cured composite than the T300 fiber. The 3000 filament yarn end T300 fiber even in the untwisted form still retains a slight twist, but nests well, permitting fabrication of high fiber volume laminates.

- Epoxy matrix materials may also behave differently when subjected to compressive buckling loads under various temperatures and moisture conditions, especially since the equilibrium moisture contents and wet glass transition temperatures (Tg) were expected to be different for these two materials.

- These materials have gained acceptance and are in the most wide spread use for aircraft structures. Therefore, a comparison data base and fabrication experience are most readily available for these two materials.

2.2 Laminate Selection

Three laminate designs were chosen for this program to be tested in the longitudinal and transverse directions which is effectively equivalent to testing six laminate types. Selection of the laminates presented in Table 1 was influenced by the following points:

- Laminate must be representative of those commonly used in structures.

- Interlaminar shear and tensile normal stresses should be minimized to prevent premature edge delamination.

TABLE 1

TEST LAMINATES

Designation	Type	No. of Plies	Layup
U1L	100% - 0° unidirectional	16	$(0)_{16}$
U1T	100% - 90° unidirectional	16	$(90)_{16}$
U2	100% - ±45°	16	$(\pm 45)_{4s}$
L1L	25% - 0°, Quasi-isotropic	16	$(0/45/90/-45_2/90/45/0)_s$
L1T	25% - 0°, Quasi-isotropic	16	$(90/-45/0/45_2/0/-45/90)_s$
L2L	67% - 0°,/33% - ±45°	24	$(0/45/0_2/-45/0_2/45/0_2/-45/0)_s$
L2T	67% - 90/33% - ±45°	24	$(90/-45/90_2/45/90_2/-45/90_2/45/90)_s$

- Symmetry about the mid-plane should be maintained to avoid warping under load or due to fabrication stresses.

- Both fiber and matrix dominated failures should be investigated.

- Laminate thickness must be such that adequate bond strength can be obtained.

- The number of plies chosen for the evaluation must provide a reasonable design offering resistance to compressive buckling.

Laminates L1 and L2 were chosen based on the above considerations. Laminate L1 was chosen because of possible wide application and because the failure mode may be dominated by the matrix. Laminate L2 was selected because the failure may be dominated by the fiber. L1 and L2 were optimized for compression and tension loading by minimizing the maximum interlaminar tensile normal stress.

The 100% - 0°, U1 laminate is one of the most difficult laminates to test in compression, therefore it was expected to reveal any problems that may be associated with the "full-fixity" fixture described in Section 1.3, while at the same time allowing comparison of compressive stress-strain curves with those obtained in tension. U2 was included in this study for the determination of the material in-plane shear properties.

2.3 Laminate Fabrication and Quality Assurance Procedures

Test laminates were fabricated in an autoclave using vacuum pressure augmented by autoclave pressure. To ensure quality and uniformity of test laminates, a detailed Quality Control Plan was prepared for this program and is included in this report as Appendix A. Manufacturing and quality assurance procedures are outlined in Table 2 and summarized as follows:

- Prepreg Quality Assurance - Resin content, volatiles content, resin gel time and flow of each prepreg batch was inspected for conformance to specified tolerances upon receipt, along with infrared analysis ensuring that separate batches were as nearly identical as possible. Prepreg material was also inspected for flaws such as fiber misalignment, breakage, gaps, excess resin, and starved areas, and any portions of the batch containing these flaws was rejected.

TABLE 2

QUALITY ASSURANCE TESTING OUTLINE

Material Form	Inspection/Test/Control
Prepreg (receiving inspection)	- Visual examination (fiber uniformity, fiber alignment, resin uniformity) - Volatiles content - Uncured resin content - Resin flow - Gel time - Infrared Analysis - Amal weight - Control of shelf life
Layup (prior to cure)	- Visual examination of excess section for proper orientation of each ply
Cured Laminates	- Visual examination (resin starvation, fiber wash-out, pinholes, etc.) - Thickness per ply - Cured resin content - Specific Gravity - Void content (calculated) - Interlaminar Shear - Longitudinal Tensile Strength & Modulus - Longitudinal Flexural Strength & Modulus - Examination of cross-section under magnification - Nondestructive inspection of each test laminate by ultrasonic "C" scan

- Layup of Laminates - Layup of laminates was performed in a semiclean room with temperature controlled to 21 ±3°C (70 ±5°F), which prevented contamination with dust or foreign matter. Controlled temperature assured proper tack and drape of prepregs and prevented water condensation problems. Fiber orientation control in a layup was accomplished by use of suitable templates to meet required angle tolerances.

- Curing of Laminates - The use of autoclave curing techniques permitted close control of pressures and temperatures. An autoclave incorporating automatic programming instrumentation to control dwell time and heating rates was used.

  Test laminate fabrication required more than one autoclave cycle, but close controls reduced the possibility of significant test panel variations.

  Bagging and bleeding methods were adjusted as required for individual resin systems. Bleeding was accomplished by use of a perforated or open mesh releasable membrane placed in contact with the laminates and backed up with an absorbent material, which permitted escape of air and volatiles as well as bleeding of resin to reduce resin content of the laminates to specified levels. Pressure bags of suitable heat resistant plastic film were sealed in place over the layup.

  An optimum cure cycle was developed prior to test laminate fabrication (see Appendix A). Proper combination of factors such as heat-up rate, dwell, venting, and time of pressure application were determined, which helped to ensure proper release of volatiles, resin flow, and wetting to minimize voids and porosity, and provide maximum resin compaction and adhesion to fibers.

  Prior to cure, an excess section of the layup was examined to ensure proper filament orientation in each ply. During the cure cycle, a complete permanent record was maintained of temperature, vacuum pressure, and autoclave pressure. This record included heat-up rates and times of pressure application and release.

- Post-Fabrication Inspection - Test laminates were visually examined for defects such as resin starvation, fiber wash-out, pinholes, voids, etc. Thickness per ply, cured resin content, and density were determined. These properties were used to estimate the void content from 25.4 mm (1.0 inch) wide strip generally near the center of each panel, perpendicular to the 0° fiber direction. Void content was determined according to ASTM D2734-70. This procedure requires accurate values for the density of fiber and neat resin. Unfortunately these values are not usually known accurately. All panels were fabricated such that a minimum of 19.1 mm (0.75 inch) wide edge could be trimmed off on all sides.

Each test laminate panel was nondestructively inspected by ultrasonic "C" scan procedure for voids, delaminations and other defects. Standard reference 0.05 mm (0.002 inch) thick Teflon film pads 3.2 to 12.7 mm (1/8 to 1/2 inch) diameter were placed in the corner of each fabricated test panel.

For all tests, coupons were fabricated and machined identically so that any scatter in test results could not be attributed to variations in coupon fabrication procedures or geometry. After fabrication and prior to testing, the thickness of all coupons was measured in eight places and the width in four places (see Figure 6 for these locations). The width of any one coupon varied at most ±0.0127 mm (±0.0005 inch) (±0.05%) within the gage length. The width of all coupons varied by less than ±0.10 mm (±0.004 inch) within the gage lengths. The area of any one coupon was found to vary by less than ±1.5% and that of all coupons by less than ±4% within the gage length.

All coupons were identified by the following system:

1	TY	1225	-	10	F - Sub-Panel Identification
Panel No. of Given Series	Mat'l & Batch Code	Autoclave Series No.		Coupon No.	

Autoclave and panel numbers are consecutive at Lockheed and are an internal reference number unique to each panel. The test panels were cut into subpanels, identified as A, B, C, D, E, F, or G. This system of coupon identification allowed for traceability of each coupon to previous panel location and of each panel to fabrication history. Specimens for the various tests were randomized by a double blind randomization process.

2.4 Program Test Matrix

The test matrix for the program is given in Table 3. To reduce the number of tests, yet develop a sound data base, one material was completely characterized in tension, shear and column compression under eight environmental conditions while the second material was subjected to two environmental conditions, the best and worst as determined from comparable tests on

TABLE 3

TEST MATRIX

Phase	Item No.	Type of Test[a]	Laminates	Materials[b]	No. of Moist. Conds/ Test Temps.[c]	No. of Laminates	No. of Column Lengths[d]	No. of Replicates	Total No. of Specimens	Total No. of Tests
I	1	LT	U1, L1, L2	1	2M/4T	3	-	3	72	72
Base	2	LT	U1, L1, L2	2	2	3	-	3	18	18
Line	3	TT	U1, L1, L2	1	2M/4T	3	-	3	72	72
Data	4	TT	U1, L1, L2	2	2	3	-	3	18	18
	5	IPS	U2	1	2M/4T	1	-	3	24	24
	6	IPS	U2	2	2	1	-	3	6	6
								TOTALS	210	210
IIa	1	LC	U1, L1, L2	1	2M/4T	3	4	3	288	504
Column	2	LC	U1, L1, L2	2	2	3	4	3	72	126
	3	LC & TC	U1, L1, L2	1	XD/1T	3	4	3	72	72
Buckling	4	LC & TC	U1, L1, L2	1	1M/1T[e]	3	4	3	72	72
Data	5	LC & TC	U1, L1, L2	1	1M/1T	3	4	6	144	144
	6	TC	U1, L1, L2	1	2M/4T	3	4	3	288	504
	7	TC	U1, L1, L2	2	2	3	4	3	72	126
IIb										
Buckling	1	LC	L1, L2	3	Room Temp.	2	4	10	80	140
Baseline Batch SY	2	TC	L2	3	Dry	1	4	10	40	70
								Totals	1128	1758
III	1	LC (NUM)	L1, L2	1 & 2	2M/2T	2	2	3	96	192
Effect of Micro-	2	LC (MC)	L1, L2[f]	3	2	3	2	3	36	72
cracks & non-uni- form mois- ture	3	TC (MC)	L2	3	2	1	2	3	12	24
								TOTALS	144	288
					PHASES I, II AND III			TOTALS	1482	2256

a - LT - Longitudinal Tension, TT - Transverse Tension. IPS - In-Plane Shear, LC - Longitudinal Compression
TC - Transverse Compression, NUM - Non-Uniform Moisture, MC- Microcracked by loading in tension to 80% of average σ_{tu}

b - 1 - T300/5208 (Batch TY) 2 - A-S/3501-5A 3 - T300/5208 (Batch SY)

c - 2M/4T - Two Conditioning Exposures (Dry 22°C (72°F) and 40% R.H., Wet: 82°C (180°F) and 90% R.H.) followed by testing at four temperatures(-54°C (-65°F), 22°C (72°F), 93°C (200°F), 135°C (275°F))

2 - 72°F, Dry; 275°F, Wet

XD/1T - Dried out at 180°F in air circulating oven, then tested in dry condition at 275°F.
1M/1T - Conditioned at 180°F and 90% R.H. and tested at 275°F.
2M/2T - Two different non-uniform moisture distributions, two test temperatures 72°F, 275°F.

d - Does not include lengths in elastic region.

e - Dried out at 180°F. in air circulating oven prior to conditioning.

f - L2 loaded to 80% and 90% of average σ_{tu}

first material. For convenience, the testing was divided into three phases, but tests were not necessarily conducted in that order.

Phase I consisted of baseline tension tests for the two material systems. For each material, the longitudinal and transverse tension and in-plane shear stress-strain response were determined for the unidirectional composite using three replicates per a moisture/temperature condition and test type. Longitudinal and transverse tension stress-strain curves were obtained for the two laminates, L1 and L2 (see Table 1), of each material with three replicates per a condition.

The Lockheed developed test method (see Section 1.3) which results in a buckling curve rather than a single compression strength was used in Phase II to evaluate the column buckling behavior of three laminates of two materials. Specimens of one material were tested in the two principal directions at seven different column lengths, including fully supported and at four temperatures after exposure to one of two moisture/temperature conditions in order to establish the basic trends of the compression/buckling curve.

Specimens of the second material were tested in two directions at seven column lengths, but under two conditions, the best and worst as determined from tests on the first material. These conditions were identified as: 1) Best 22°C (72°F) after dry conditioning (22°C (72°F) and 40% R.H.) and 2) Worst: 135°C (275°F) after wet conditioning (82°C (180°F) and 90% R.H.).

Four coupons were required for each set of seven column length test points: one fully supported and three others each to be tested first at an elastic column length and then at an inelastic column length. The assumption was made that specimens tested in the elastic region can be retested to obtain a point on the inelastic buckling curve. The validity of this assumption was checked by a series of tests prior to the initiation of testing and verified by tests conducted in Phase IIb.

Generally, three replicates per test condition were used throughout the program. Although three replicates at each column length are inadequate to precisely determine the extent of scatter at each column length, a type of

pooling of data obtained at different lengths is possible by comparing the average curves representing buckling strength versus column length which are based on 21 points for each material/laminate combination per test condition. This approach was considered acceptable because the primary purpose of this program was to establish the effects on the compression buckling strength caused by changes in specific variables, not the production of design data. Tests of items IIa-5 and IIb-1,2 supported this approach by providing 6 to 10 additional specimens at the inelastic column lengths for laminates at 22°C (72°F), dry, and six specimens for laminates at 135° (275°) wet, so that the degree of data dispersion was more precisely defined.

After fabrication, all specimens were kept in a chamber maintained at 22°C (72°F) and 40% R.H. until a stable moisture content of ~ 0.3% was attained. This was considered the reference or "dry" room temperature conditioning exposure, although the actual moisture content was determined. Specimens tested in the "wet" condition were further exposed to 82°C (180°F) and 90% R.H. for a given time period (~10 weeks) until a uniform moisture content was attained. The amount of moisture lost during the elevated temperature testing was determined from either weight loss coupons placed in the test chamber or from samples cut from the test specimen. Specimens were tested at temperatures of -55°C (-65°F), 22°C (72°F), 93°C (200°F) and a temperature above the "wet" T_g, (135°C (275°F)). The "wet" T_g was determined for both materials on specimens that were conditioned at 82°C (180°F) and 90% R.H.

The effects of drying and subsequent reconditioning of coupons on column compression behavior were evaluated at 135°C (275°F) in items 4 and 5 of Phase II.

Effects of two non-uniform moisture distributions were evaluated in Phase III along with the influence of microcracks on column buckling behavior. One set of specimens was conditioned such that both outside surfaces were at a higher moisture content than the center, and a second set so that the moisture content on one surface was higher than on the other. The latter was accomplished by having one side and edges sealed during the conditioning

exposure. These specimens were then tested at 22°C (72°F) after dry conditioning and at 135°C (275°F) after wet conditioning.

Effects of microcracks on buckling and compression strength were assessed by preloading twelve speciment each of T300/5208 laminates L1L, L2L and L2T to 80% of the average tensile strength, and another 12 specimens of L2L to 90% of average σ_{ut}. All the specimens were subjected to dry conditioning after which one-half were further conditioned at 82°C (180°F) and 90% R.H. Moisture content and distribution were determined after ~10 weeks of conditioning. Selected specimens were inspected by optical microscopy to ascertain the extent of microcracking. Specimens in Phase III were tested at four column lengths for a total of twelve data points per curve.

Moisture distribution for specimens in all three testing phases was determined by a Lockheed developed delamination technique described in Section 4.3.

Linear thermal expansion was measured over the range of -54°C (-65°F) to 177°C (350°F) in the longitudinal and transverse directions for the three laminates of both test materials using a tube type dilatometer constructed and operated in accordance with ASTM E228.

Selected specimens were subjected to failure analysis. Specimens were examined by optical microscopy to aid in the identification of failure modes and in the analysis of the mechanics of the failure process.

2.5 Conditioning

After fabrication, all coupons were kept in a conditioning chamber maintained at 22° 1°C (72° ±2°F) and 40 ±10% relative humidity in a laboratory air environment. This conditioning stabilized the coupons at a standard room temperature dry condition. Six of the coupons were used to monitor moisture pickup. Moisture distributions were obtained on two of these coupons after 14 days, 90 days and towards the end of the testing phase.

Composite structures fabricated under standard manufacturing conditions will always contain a certain amount of moisture. Therefore, the above procedure was implemented in preference to drying of the specimens as a more realistic reference condition. Specimens exposed to ambient conditions during manufacturing after panel fabrication have been found to contain ~ 0.3% moisture.

Coupons to be tested at a higher moisture content were removed from the room temperature conditioning environment after a minimum of 2 weeks exposure and conditioned at 82°C (180°F) in 90% R.H. until a new uniform moisture distribution through the thickness was obtained with the exception of the 96 coupons tested with a non-uniform moisture distribution which were removed after one week. Coupons were conditioned in five batches so that no coupon remained in the high temperature environment for an excessive time prior to testing. At least six coupons (three of each material) in each batch were used to monitor moisture pickup. After stabilization was reached, the actual moisture content and moisture distributions were obtained, using the delamination technique described in Section 4.3. Additionally, several weight loss coupons were also placed unloaded in a test chamber after conditioning to determine if any significant change in moisture content occurred during the compression testing. Moisture distributions were also obtained from samples taken from the test specimens after failure.

2.6 Test Conditions

All tests were conducted in 0.27 and 0.53 MN (60 and 120 kip) Baldwin static test machines. Compression and column buckling tests were conducted according to the method outlined in Section 1.3. Load and deflection readings were continuously read out on a X-Y recorder. Due to the large number of specimens tested, extensometer data were taken on the fully supported, zero column length tests with crosshead motion being recorded for the others. The in-plane shear specimens for Phase I were instrumented with strain gages. For these specimens, stress-strain curves were machine plotted by digital computer equipment using appropriate load scaling factors and extensometer

gage lengths. Ultimate strengths were also automatically calculated and tabulated by the computer. All room temperature tests were conducted at 22° ±1°C (72° ±2°F), 40 ±10% R.H. Elevated temperature tests were run at 93°C (200°F), and also at 135°C (275°F), which is above the wet T_g of both materials (T300/5208 and AS/3501-5A). The T_g was determined by dilatometry and penetration; moisture loss during these tests is less than with other methods (see Section 4.2).

During the tests, temperature in the chamber which surrounded the specimen was controlled by means of thermocouples attached to the specimen and leading to a temperature recorder. Heated air was blown into the chamber for high temperature test and liquid nitrogen was used to obtain the -54°C (-65°F) temperature. The tests were run at a "static" cross-head speed of 1.27 mm/min (0.05 in./min).

Close attention was given to test variables which, if not closely controlled, add to data "scatter". This included:

- Periodic verification of all test machine calibrations.
- Use of trained technicians.
- Close control of specimen alignment and other specimen installation variables.

3. MATERIAL CHARACTERIZATION

Three panels each of laminates L1, L2, U1 and one of laminate U2 of T300/5208 batch TY, two panels each of laminates L1 and L2 of T300/5208 batch SY, four panels of laminate L2 and one each of U1, U2 and L1 of AS/3501-5A batch TJ were fabricated according to the procedure outlined in the Quality Control Plan of Appendix A. Panel layouts are displayed in Appendix B. The cure cycles described in Appendix A were established after preliminary cure evaluations were conducted on two throw-away panels for each material.

There were no indications of any type on the C-scan records for the panels from which test coupons were machined, therefore, the C-scan records are not reproduced in this report.

3.1 Evaluation of T300/5208 Material

Two 305 x 305 mm (12 x 12 inch) cure trial panels were fabricated, one with and one without a prebleed cycle. The thickest, 24-ply 67% 0° fiber laminate $(0/+45/0_2/-45/0_2/+45/0_2/-45/0)_S$ was selected for the evaluation. Panels were examined by ultrasonic C-scan then sectioned and subjected to metallographic examination. These fabrication methods produced essentially equivalent panels which met the requirements of the Quality Assurance Plan (Appendix A). The fiber volumes for the panels with and without prebleed, respectively were 63.9% and 64%. Metallographic sections showed the panels to be free of significant void formations or other defects. Therefore, the shorter cycle without prebleed was chosen for this program.

During the 11-day Lockheed Plant shutdown for the 1978 Christmas holidays, the freezer containing the T300/5208 material malfunctioned resulting in a temperature rise above freezing. As a result of discussions with the Air Force Technical Monitor it was decided that this material should not be used for this program. A new batch of material was ordered at no cost to the contract to replace the questionable batch which no longer conformed to the provisions of the Quality Assurance Plan. A few rolls were stored in a different freezer thereby surviving the malfunction and were used to fabricate panels for the Phase IIb buckling baseline specimens and the microcracked specimens. This original batch is designated by the Lockheed batch code as SY.

Both the replacement batch of material procured from Narmco Materials, Inc. designated as batch TY and batch SY were inspected and found to meet all requirements for batch accpetance. Quality Control test data are given in Tables 4 and 5.

3.2 Evaluation of AS/3501-5A

The AS/3501-5A graphite/epoxy material designated as batch TJ was inspected and passed the batch acceptance tests. Results of the Quality Control tests are given in Table 6.

Two cure cycles suggested by the material producer, Hercules, Inc., were evaluated for use in this program. Two 305 x 305 mm (12 x 12 in.) 24-ply, 67% 0° fiber panels $(0/+45/0_2/-45/0_2/+45/0_2/-45/0)_S$ were fabricated. Panel 1TJ1169 was fabricated according to the cycle given in Table 7a and 1TJ1210 was fabricated using the cycle shown in Table 7b. The ultrasonic C-scan results for 1TJ1169 and 1TJ1210 are shown in Figures 11 and 12, respectively. The second cycle with the 1-hour dwell at 121°C (250°F) was expected to result in a much better quality panel, however the C-scan indications appear very similar for both panels. To identify the cause of the line indications on the C-scan record, panels were sectioned for metallographic examination at 0°, 90° and 45° to the indications as marked on the C-scan. As can be seen from both 0° and 90° sections in Figures 13 through 18 the C-scan indications for panel 1TJ1169 appear to correspond to a large

TABLE 4a

SUMMARY OF LOCKHEED QUALITY CONTROL TESTS FOR NARMCO RIGIDITE 5208-#300 MATERIAL BATCH #1079 (TY)

Material Property	Specification Requirements C-22-1379/111	Measured Property	Accepted
	UNCURED PROPERTIES		
1. Areal Fiber Weight (4 req)	139 - 149 g/m^2	143 g/m^2	X
		144 "	X
		145 "	X
		144 "	X
		Ave. 144 "	
2. Infrared Spectrophotometric Anal. (1 req)	Conformance to file spectrogram	-	X
3. Volatiles (2 req) 60± 5 min at 350°	2% Maximum	0.3% edge	X
		0.35% center	X
4. Dry resin content (4 req) (Soxhlet)	38 - 44%	43.1% left	X
		43.4% left center	X
		43.1% right center	X
		44.0% right	X
5. Resin Flow at 350°F and 85 psi (2 req)	15 - 29%	19.0%	X
		18.9%	X
6. Gel Time at 350°F (2 req)	For information only	20.0 minutes	-
		20.3 minutes	-
7. Fiber Orientation	0°	-	X
	CURED LAMINATES		
1. Cured Fiber Volume 16 ply panel (3 req)	60 - 68%	62.3	X
		65.0	X
		65.4	X
		Ave. 64.2%	
2. Cured Fiber Volume, 8 ply panel (3 req)	60 - 68%	64.5	X
		64.5	X
		65.2	X
		Ave. 64.7%	
3. Specific Gravity, 16 ply panel (3 req)	1.55 - 1.62	1.57	X
		1.57	X
		1.58	X
		Ave. 1.57	

TABLE 4a

SUMMARY OF LOCKHEED QUALITY CONTROL TESTS FOR NARMCO
RIGIDITE 5208-#300 MATERIAL BATCH #1079 (TY)

Material Property	Specification Requirement C-22-1379/111	Measured Property	Accepted
4. Specific Gravity, 8 ply panel (3 req)	1.55 - 1.62	1.57	X
		1.57	X
		1.58	X
		Ave. 1.57	
5. Tensile Strength, Longitudinal at 75°F (3 req)	170 ksi min.	227	X
		119	X
		223	X
		Ave. 216 ksi	
6. Elastic Modulus longitudinal at 75° (3 req)	$20 \cdot 10^6$ psi min.	$20.6 \cdot 10^6$	X
		$20.0 \cdot 10^6$	X
		$21.0 \cdot 10^6$	X
		Ave. $20.5 \cdot 10^6$	
7. Flexural Strength at 75°F (3 req)	210 ksi min.	255	X
		245	X
		264	X
		Ave. 254 ksi	
8. Flexural Modulus at 75°F (3 req)	$18 \cdot 10^6$ psi min.	18.0	X
		18.1	X
		18.2	X
		Ave. $18.1 \cdot 10^6$ psi	
9. Flexural Strength at + 180°F (3 req)	200 ksi min.	224	X
		238	X
		231	X
		Ave. 231 ksi	
10. Flexural Modulus at + 180°F (3 req)	$16 \cdot 10^6$ psi min.	$18.4 \cdot 10^6$	X
		$19.7 \cdot 10^6$	X
		$20.0 \cdot 10^6$	X
		Ave. $19.4 \cdot 10^6$ psi	
11. Short Beam Shear Strength at 75° (3 req)	13 ksi min.	16.7	X
		15.6	X
		16.7	X
		Ave. 16.3 ksi	

TABLE 4a

SUMMARY OF LOCKHEED QUALITY CONTROL TESTS FOR NARMCO
RIGIDITE 5208-#300 MATERIAL BATCH #1079 (TY)

Material Property	Specification Requirements C-22-1379/111	Measured Property	Accepted
12. Short Beam Shear Strength at + 180°F (3 req)	12 ksi min	13.2	X
		13.6	X
		13.4	X
		Ave. 13.4 ksi	
13. Thickness per ply, 16 ply panel (5 req)	0.0046 - 0.0056 inch	0.0048	X
		0.0048	X
		0.0050	X
		0.0048	X
		0.0051	X
		Ave. 0.0049 inch	
14. Thickness per ply, 8 ply panel (5 req)	0.0046 - 0.0056 inch	0.0050	X
		0.0051	X
		0.0050	X
		0.0050	X
		0.0051	X
		Ave. 0.0050 inch	

TABLE 4b

SUMMARY OF THE NARMCO QUALITY CONTROL TESTS FOR RIGIDITE 5208-T300
CERTIFIED TEST REPORT NO. 34776 (Lockheed batch TY)

TESTING RESULTS

ITEM # 1
MATERIAL: Rigidite 5208-T300 12"
Batch # 1079

Roll	Amount	Resin Content	Areal Fiber Weight	Mfg. Date	Test Date
10	24.2	41	144 grams/sq.meter	1-12-78	1-17-78
11	26.2	42	144		
12	25.7	41	144		
13	25.4	42	143		
14	25.6	40	144		
15	21.5	42	144		
16	21.5	41	144		
17	26.7	43	144		

Flow:	22%
Volatiles:	0.2%
Gel Time:	19.53 min. @ 350°F.
Tack:	Acceptable
Specific Gravity:	1.58/1.58/1.58: 1.58 g/cc avg.
Cured Fiber Volume:	66/66/66: 66% average
RT Long. Tensile Strength:	218,360/244,290/255,560: 239,400 psi avg.
RT Long. Tensile Modulus:	20.43/21.96/21.49: 21.29 x 10^6 psi avg.
RT Long. Flex Strength:	282,390/292,310/271,300: 282,010 psi avg.
180°F. Long. Flex Strength:	273,050/298,270/247,490: 272,940 psi avg.
RT Long. Flex Modulus:	23.25/22.74/22.15: 22.71 x 10^6 psi avg.
180°F. Long. Flex Modulus:	24.30/23.16/21.95: 23.13 x 10^6 psi avg.
RT Short Beam Shear:	18,000/17,830/17,830: 17,890 psi avg.
180°F. Short Beam Shear:	15,040/14,840/15,670: 15,190 psi avg.
Cured Ply Thickness:	0.0047"
Discrepancy Sheets:	Attached

TABLE 5a

SUMMARY OF LOCKHEED QUALITY CONTROL TESTS FOR NARMCO
RIDIGITE 5208-T300 MATERIAL BATCH **#1015 (SY)**

Material Property	Specification Requirements C-22-1379/111	Measured Property	Accepted
	UNCURED PROPERTIES		
1. Areal Fiber Weight (4 req)	139 - 149 g/m^2	144 g/m^2	X
		140 "	X
		139 "	X
		139 "	X
		Ave. 141 "	
2. Infrared Spectrophotometric Anal. (1 req)	Conformance to file spectrogram	-	X
3. Volatiles (2 req) 60± 5 min at 350°F	2% Maximum	0.4% edge	X
		0.4% center	X
4. Dry resin content (4 req) (Sophlet)	38 - 44%	43.4% left	X
		42.6% left center	X
		44.0% right center	X
		42.8% right	X
5. Resin Flow at 350°F and 85 psi (2 req)	15 - 29%	20.3%	X
		21.7%	X
6. Gel Time at 350°F (2 req)	For information only	20.3 minutes	-
		21.2 minutes	-
7. Fiber Orientation	0°	-	X
	CURED LAMINATES		
1. Cured Fiber Volume 16 ply panel (3 req)	60 - 68%	67.8	X
		68.0	X
		67.9	X
		Ave. 67.9%	
2. Cured Fiber Volume. 8 ply panel (3 req)	60 - 68%	67.9	X
		67.9	X
		67.4	X
		Ave. 67.7%	
3. Specific Gravity 16 ply panel (3 req)	1.55 - 1.62	1.60	X
		1.60	X
		1.60	X
		Ave. 1.60	

TABLE 5a

SUMMARY OF LOCKHEED QUALITY CONTROL TESTS FOR NARMCO RIDIGITE 5208-T300 MATERIAL BATCH #1015 (SY)

Material Property	Specification Requirements C-22-1379/111	Measured Property	Accepted
4. Specific Gravity, 16 ply panel (3 req)	1.55 - 1.62	1.60	X
		1.60	X
		1.60	X
		Ave. 1.60	
5. Tensile Strength, longitudinal at 75°F (3 req)	170 ksi min.	206	X
		208	X
		205	X
		Ave. 207 ksi	
6. Elastic Modulus, longitudinal at 75°F (3 req)	$20 \cdot 10^6$ psi min.	$22.4 \cdot 10^6$	X
		$21.0 \cdot 10^6$	X
		$20.8 \cdot 10^6$	X
		Ave. $21.4 \cdot 10^6$	
7. Flexural Strength at 75°F (3 req)	210 ksi min.	254	X
		265	X
		281	X
		Ave. 269 ksi	
8. Flexural Modulus at 75°F (3 req)	$18 \cdot 10^6$ psi min.	19.3	X
		18.8	X
		19.9	X
		Ave. $19.2 \cdot 10^6$ psi	
9. Flexural Strength at + 180°F (3 req)	200 ksi min.	258	X
		241	X
		245	X
		Ave. 248 ksi	
10. Flexural Modulus at + 180°F (3 req)	$16 \cdot 10^6$ psi min.	$19.2 \cdot 10^6$	X
		$20.0 \cdot 10^6$	X
		$18.3 \cdot 10^6$	X
		Ave. $19.2 \cdot 10^6$ psi	
11. Short Beam Shear Strength at 75° (3 req)	13 ksi min.	16.9	X
		18.2	X
		17.3	X
		Ave. 17.5 ksi	

TABLE 5a

SUMMARY OF LOCKHEED QUALITY CONTROL TESTS FOR NARMCO
RIDIGITE 5208-T300 MATERIAL BATCH **#1015 (SY)**

Material Property	Specification Requirements C-22-1379/111	Measured Property	Accepted
12. Short Beam Shear Strength at + 180°F (3 req)	12 ksi min	15.0	X
		14.4	X
		14.6	X
		Ave. 14.7 ksi	
13. Thickness per ply, 16 ply panel (5 req)	0.0046 - 0.0056 inch	0.0046	X
		0.0047	X
		0.0046	X
		0.0047	X
		0.0047	X
		Ave. 0.0047 inch	
14. Thickness per ply, 8 ply panel (5 req)	0.0046 - 0.0056 inch	0.0046	X
		0.0048	X
		0.0046	X
		0.0048	X
		0.0046	X
		Ave. 0.0047 inch	

TABLE 5b

SUMMARY OF THE NARMCO QUALITY CONTROL TESTS FOR RIGIDITE 5208-T300[16]
CERTIFIED TEST REPORT NO. 34255 (Lockheed Batch SY)

MATERIAL: Rigidite 5208-T300
Batch # 1015

Roll	Amount	Resin Content	Areal Fiber Weight	Mfg. Date	Test Date
20	25.3 lbs.	44%	142 grams/sq.meter	9-30-77	10-6-77
21	24.4	42	146		
22	24.5	41	146		
23	22.6	42	145		
24	22.6	42	145		
25	23.1	43	144		
26	24.5	42	145		
27	26.1	44	145		

Flow:	25%
Volatiles:	0.3%
Gel Time:	25.40 minutes @ 350°F.
Tack:	Acceptable
Specific Gravity:	1.58/1.58/1.59: 1.58 g/cc average
Cured Fiber Volume	66/65/68: 67% average
RT Long. Tensile Strength:	257,780/205,760/231,140: 231,560 psi avg.
RT Long. Tensile Modulus:	22.55/20.92/22.29: 21.92 x 10^6 psi avg.
RT Long. Flex Strength:	235,310/261,280/224,920: 240,500 psi avg.
180°F. Long. Flex Strength:	243,000/260,630/226,690: 243,440 psi avg.
RT Long. Flex Modulus:	20.95/19.97/21.67: 20.86 x 10^6 psi avg.
180°F. Long. Flex Modulus:	19.55/18.80/19.36: 19.24 x 10^6 psi avg.
RT Short Beam Shear:	19,760/18,410/20,970: 19,710 psi average
180°F. Short Beam Shear:	15,730/17,400/16,620: 16,590 psi average
Cured Ply Thickness:	0.0047"
Discrepancy sheets:	Attached

TABLE 6a.

SUMMARY OF LOCKHEED QUALITY CONTROL TESTS FOR HERCULES A-S/3501-5A MATERIAL LOT 674 (TJ)

Material Property	Specification Requirements C-22-1379/111	Measured Property	Accepted
	UNCURED PROPERTIES		
1. Areal Fiber Weight (4 req.)	139 - 149 g/m^2	142 g/m^2	
		153 "	
		149 "	
		136 "	
		Ave. 145 "	X
2. Infrared Spectrophotometric Anal. (1 req.)		Filed	X
3. Volatiles (2 req.) 60 ± 5 min at 350°F	2% Maximum	1.21% edge	X
		1.13% center	X
4. Dry resin content (4 req.) (Soxhlet)	40 - 46% [1]	46.2% left	
		44.2% left center	
		44.4% right center	
		44.5% right	
		Ave. 44.8	X
5. Resin Flow at 350°F and 85 psi (2 req.)	15 - 29%	21.5%	X
		22.2%	X
6. Gel Time at 350°F (2 req.)	For information only	5.2 minutes	-
		5.0 minutes	-
7. Fiber Orientation	0°	-	X
	CURED LAMINATES		
1. Cured Fiber Volume, 16 ply panel (3 req.)	60 - 68%	60.5	
		60.1	
		60.9	
		Ave. 60.5%	X
2. Cured Fiber Volume, 8 ply panel (3 req.)	60 - 68%	61.3	
		60.8	
		61.4	
		Ave. 61.2%	X
3. Specific Gravity, 16 ply panel (3 req.)	1.55 - 1.62	1.56	
		1.56	
		1.56	
		Ave. 1.56	X

[1] This requirement was modified for the A-S fiber due to the higher fiber density - A-S - 1.82 g/cc T300 - 1.75 g/cc.

TABLE 6a.

SUMMARY OF LOCKHEED QUALITY CONTROL TESTS FOR HERCULES A-S/3501-5A MATERIAL LOT 674 (TJ) (Continued)

	Material Property	Specification Requirements C-22-1379/111	Measured Property	Accepted
4.	Specific Gravity, 16 ply panel (3 req.)	1.55 - 1.62	1.56 1.56 1.56 Ave. 1.56	X
5.	Tensile Strength, longitudinal at 75°F (3 req.)	170 ksi min.	211 226 256 Ave. 231 ksi	X
6.	Elastic Modulus, longitudinal at 75°F (3 req.)	$20 \cdot 10^6$ psi min.	$20.8 \cdot 10^6$ $21.2 \cdot 10^6$ $20.2 \cdot 10^6$ Ave. $10.7 \cdot 10^6$	X
7.	Flexural Strength at 75°F (3 req.)	210 ksi min.	249 251 242 Ave. 247 ksi	X
8.	Flexural Modulus at 75°F (3 req.)	$18 \cdot 10^6$ psi min.	18.6 18.3 19.1 Ave. $18.7 \cdot 10^6$ psi	X
9.	Flexural Strength at + 180°F (3 req.)	200 ksi min.	246 245 229 Ave. 240 ksi	X
10.	Flexural Modulus at + 180°F (3 req.)	$16 \cdot 10^6$ psi min.	$18.9 \cdot 10^6$ $19.5 \cdot 10^6$ $19.9 \cdot 10^6$ Ave. 19 [illegible] 10^6 psi	X
11.	Short Beam Shear Strength at 75°F (3 req.)	13 ksi min.	18.4 18.8 18.1 Ave. 18.5 ksi	X
12.	Short Beam Shear Strength at + 180°F	12 ksi min.	15.4 15.2 15.1 Ave. 15.2 ksi	X
13.	Thickness per ply, 16 ply panel (5 req.)	0.0046 - 0.0056 inch	.0046 .0046 .0050 .0049 .0050 Ave. .0048 inch	X
14.	Thickness per ply, 8 ply panel (5 req.)	0.0046 - 0.0056 inch	.0049 .0050 .0050 .0049 .0050 Ave. .0050 inch	X

TABLE 6b

HERCULES INCORPORATED QUALITY ASSURANCE LOT DATA REPORT
Lockheed Batch TJ

Lot No: 674

Spool No: 1

I. Fiber Properties

Tensile Strengh	461 psi x 10^3
Tensile Modulus	33.5 psi x 10^6
Wt./Unit Length	44.73 lb/in x 10^{-6}
Density	0.0657 lb/in^3

II. Prepreg Physical Properties

Spool No.	1
Resin Flow, %	29
Gel @350°F., min.	6
Volatiles, %	0.60
Tack	Conforms

III. Laminate Mechanical Properties	Panel No.	Test Value Average/Minimum
0° Tensile Strength, RT, ksi	5539	227/206
0° Tensile Modulus, RT, msi	5539	20.2/19.8
0° Flex Strength, RT, ksi	5540	246/234
0° Flex Strength, 180°F, ksi	5540	257/245
0° Flex Modulus, RT, msi	5540	18.3/18.2
0° Flex Modulus, 180°F, msi	5540	18.5/17.8
Short Beam Shear, RT, ksi	5540	18.0/17.0
Short Beam Shear, 180°F, ksi	5540	16.7/16.2

IV. Panel Physical Properties

Panel No.	5539	5540
Fiber Volume, %	62.1	60.2
Resin Content, %	29.97	31.69
Density (lb/in^3)	0.0582	0.0579
Void Content, %	0.10	0.04
Ply Thickness, Inches	0.0049	0.0051

V. Individual Spool Physical Properties

Spool No.	1
Resin Content, %	45
Fiber Areal Weight, gm/m^2	146

TABLE 7a

CURE CYCLE FOR PANEL 1TJ1169

1. Heat to 350°F under full vacuum at 3-1/2° to 5° per minute.
2. At 275°F apply 85 psi and continue to heat.
3. Cure for 4 hours at 350°F.

TABLE 7b

CURE CYCLE FOR PANEL 1TJ1210

1. Heat to 250°F under full vacuum at 3° to 5° per minute.
2. Dwell at 250°F 1 hour under vacuum only.
3. Apply 85 psi.
4. Heat to 350°F at 3° to 5° per minute.
5. Cure 4 hours at 350°F.

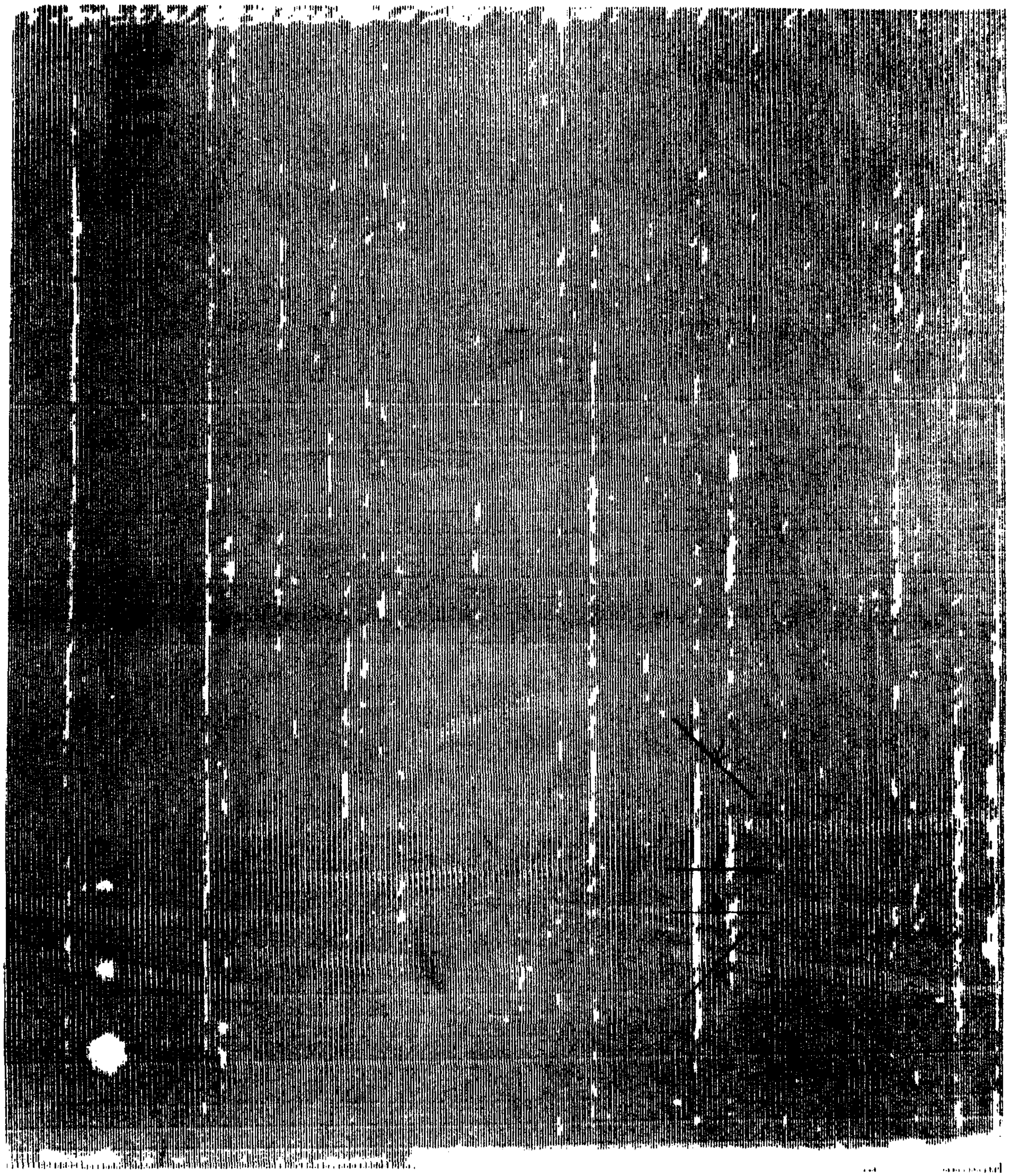


Figure 11. - Ultrasonic C-scan of panel 1TJ1169. Lines mark locations of metallographic sections.

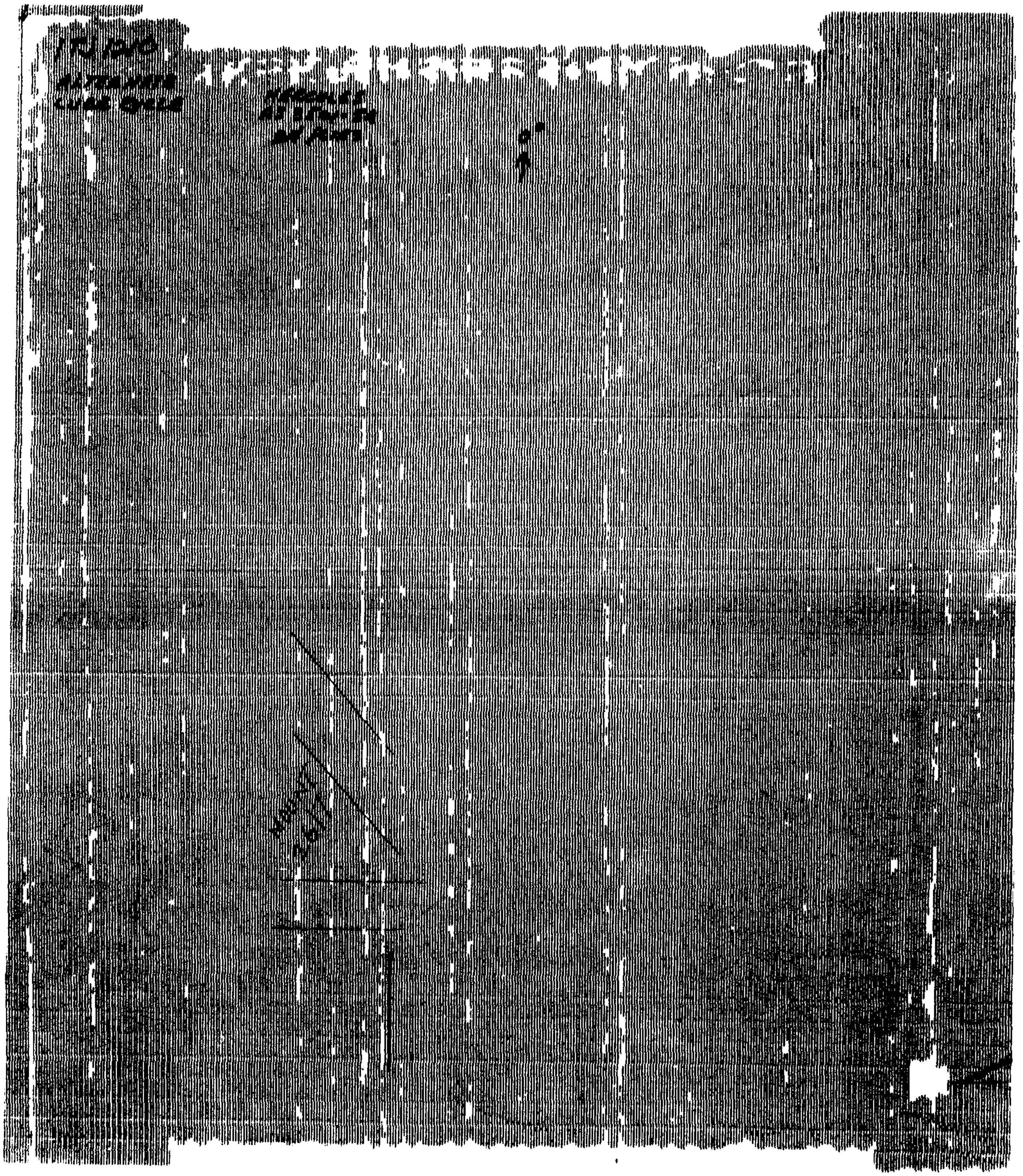
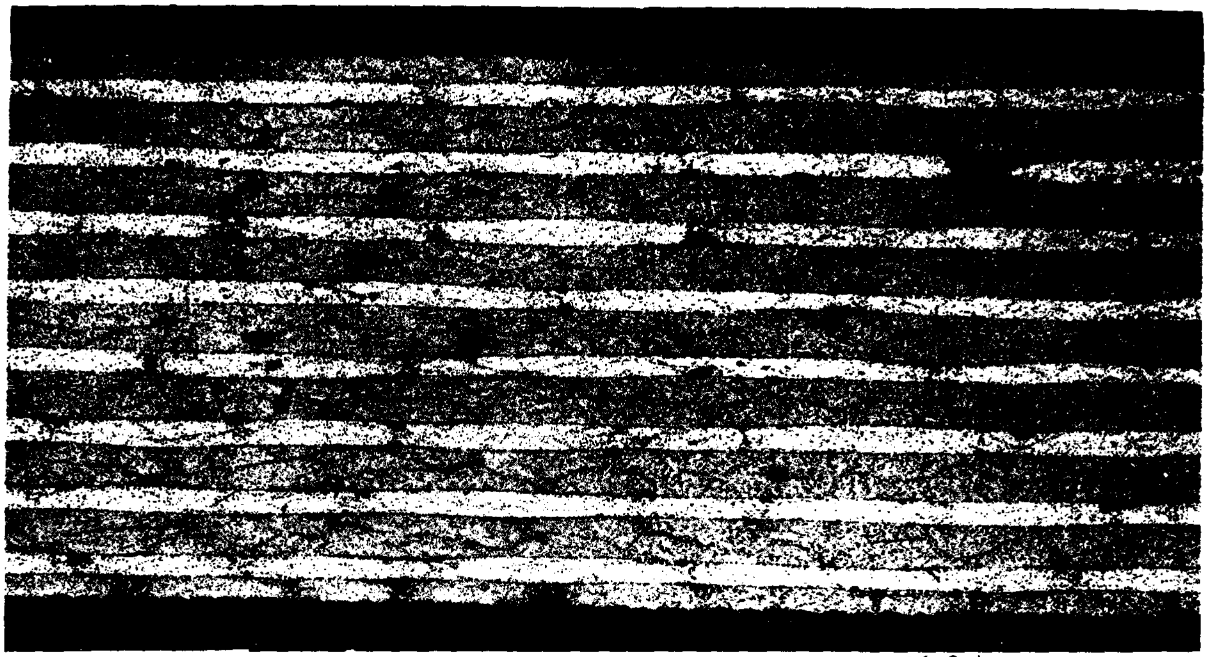


Figure 12. - Ultrasonic C-scan of panel 1TJ1210. Lines mark locations of metallographic sections.



2618-4-1 25X

Figure 13. - Metallographic section of panel 1TJ1169, cut at 90° to ultrasonic indications showing a large number of voids.

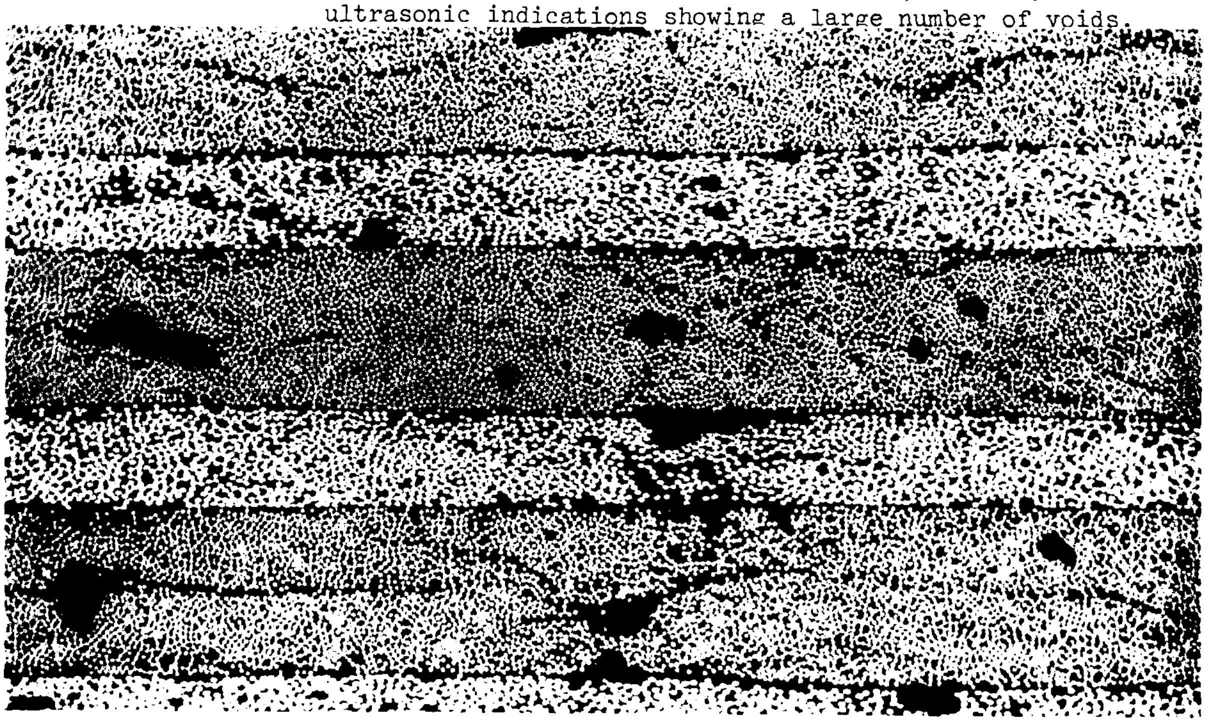
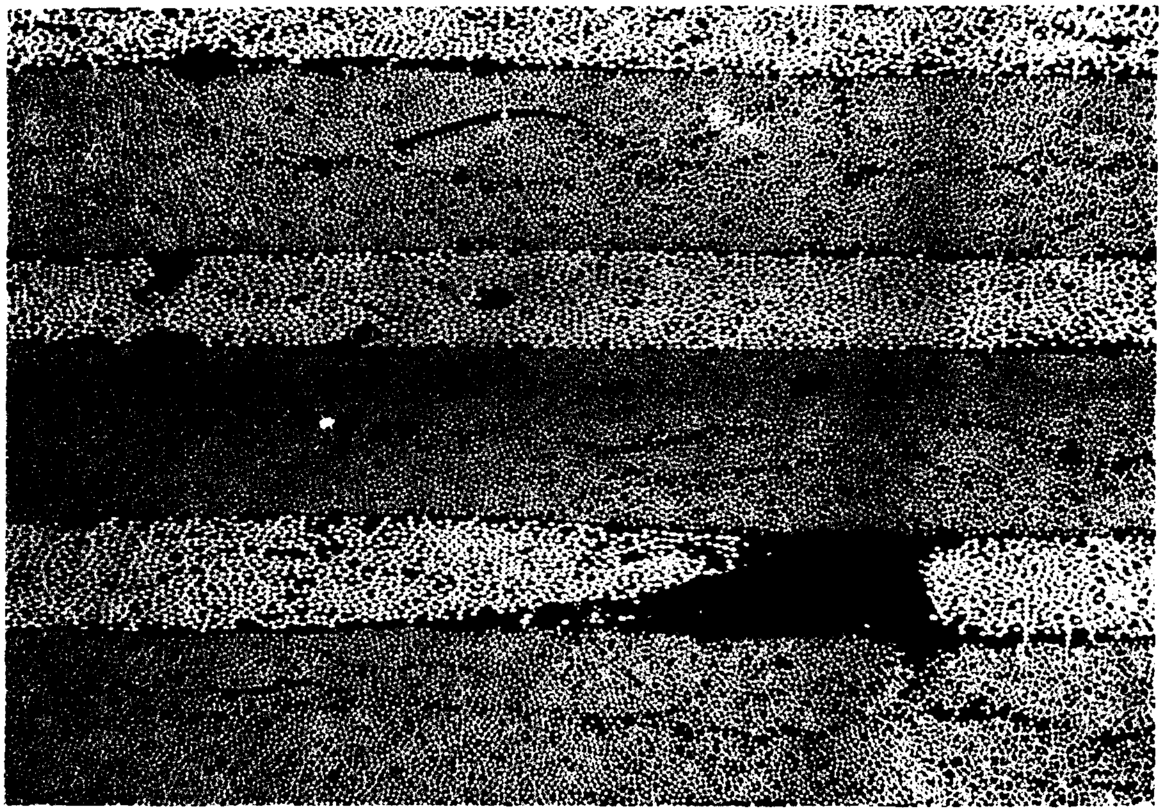
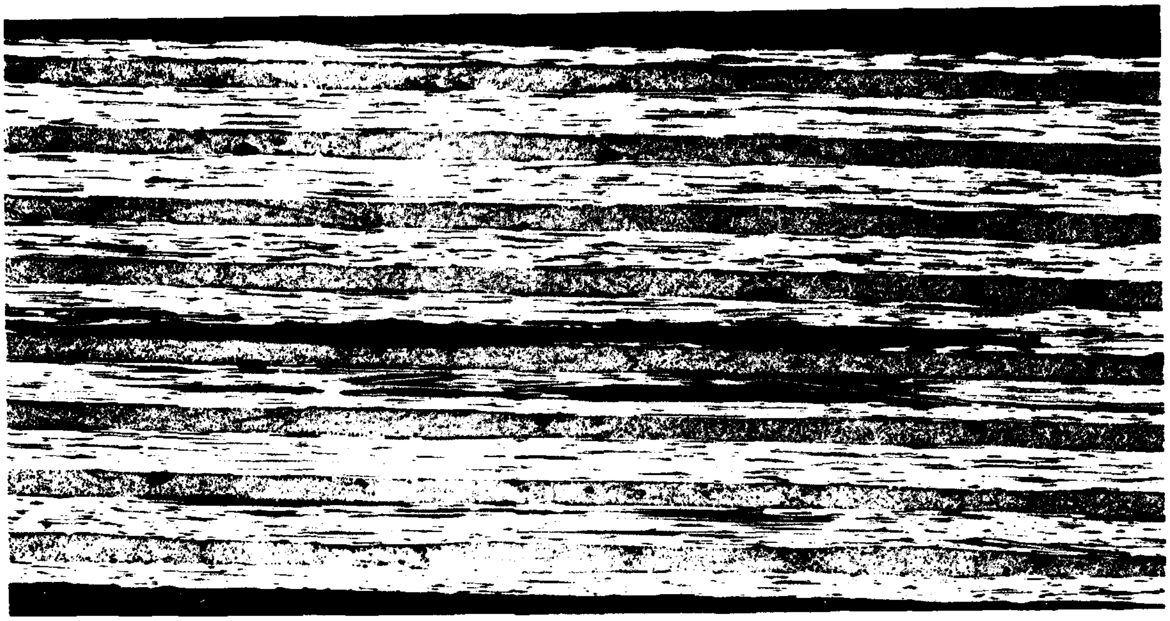


Figure 14. - Transverse metallographic section of panel 1TJ1169 at higher magnification showing large number of voids.



2618-4-2 100X

Figure 15. - 90° section of panel 1TJ1169 showing large void areas and two large diameter hollow fibers.



2618-1-1 25X

Figure 16. - Metallographic section of panel 1TJ1169 cut at 0°
to ultrasonic indications showing a large void (0.210")
in the 12th ply and numerous small ones.

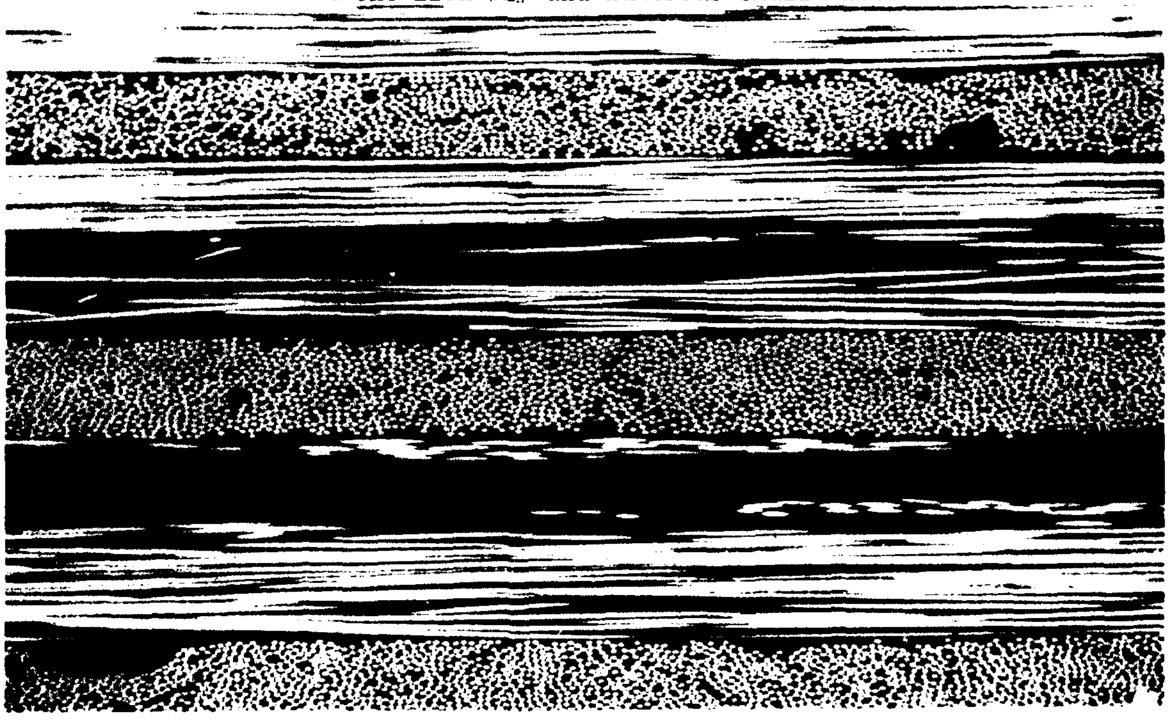


Figure 17. - Higher magnification of large void in figure 2.6.

number of elongated voids in the resin matrix. No voids were apparent in the 90° sections of panel 1TJ1210. A typical 90° section of 1TJ1210 is shown in Figure 19. However, voids are evident in the longitudinal sections of panel 1TJ1210 shown in Figures 20 through 22. Examination of the higher magnifications in Figures 23 through 27 reveals the fact that these voids are present in large diameter fibers and not in the matrix material. Forty-five degree sections in Figures 28 through 35 more dramatically display the presence of these large diameter hollow fibers which usually appear to be surrounded by resin rich areas. In fact, in Figures 32 and 33, the large filled fiber seems to have maintained a separation between two plies. Note that in all of these sections of panel 1TJ1210 there are no voids evident in the resin matrix. Subsequent panels from which test specimens were machined did not reveal comparable indications on the C-scan records.

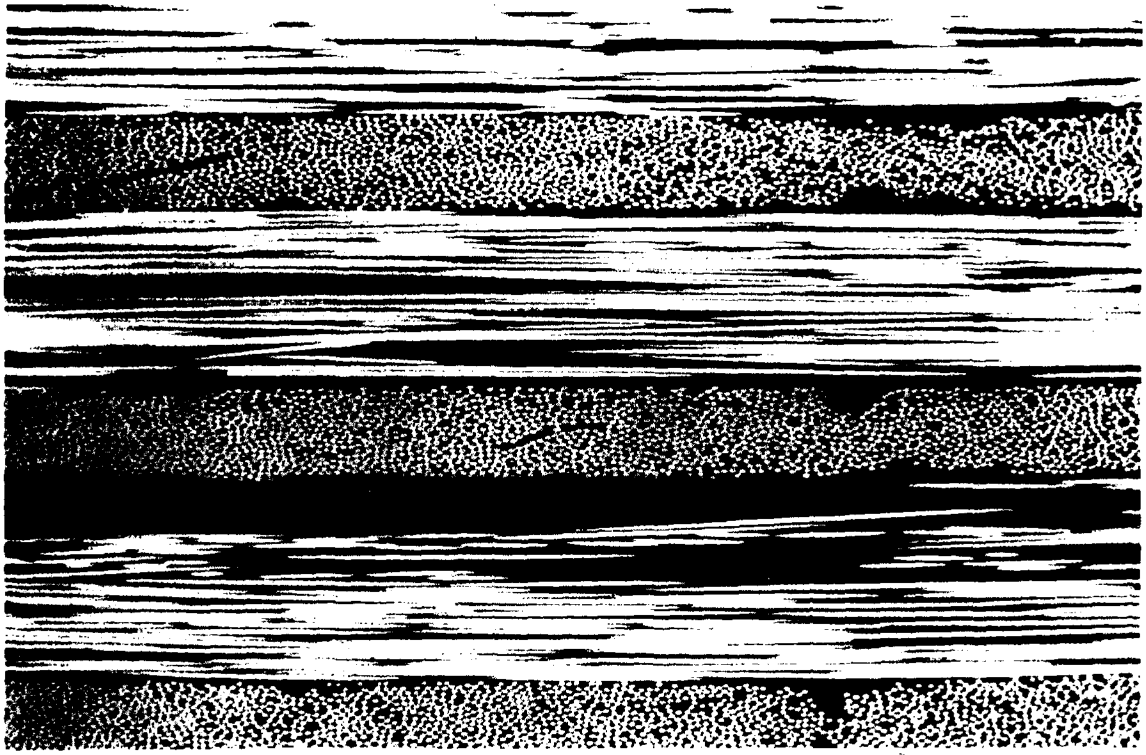
3.3 Fiber Volume and Void Content Determination Results

Fiber properties as reported by Union Carbide for the lots used in Narmco batches 1015 (SY) and 1079 (TY) along with those for the Hercules AS fiber are given in Table 8. The average fiber density for each material batch was used in the fiber volume and void content determinations. Results for the fiber, resin and void analysis of the T300/5208 panels tested in Phases I, IIa and III-1 and Phases IIb and III-2,3 are given in Tables 9 and 10, respectively and for the AS/13501-5A material in Table 11. Experimental determination of the fiber volume was conducted by Delsen Testing Laboratories, Inc., Glendale, California, in accordance with ANSI/ASTM D3171-73, Procedure A, entitled "Fiber Content of Reinforced Resin Composites" with the following exceptions:

a. Specimen size was approximately 1 gm rather than 0.3 gm. to obtain a more representative sample.

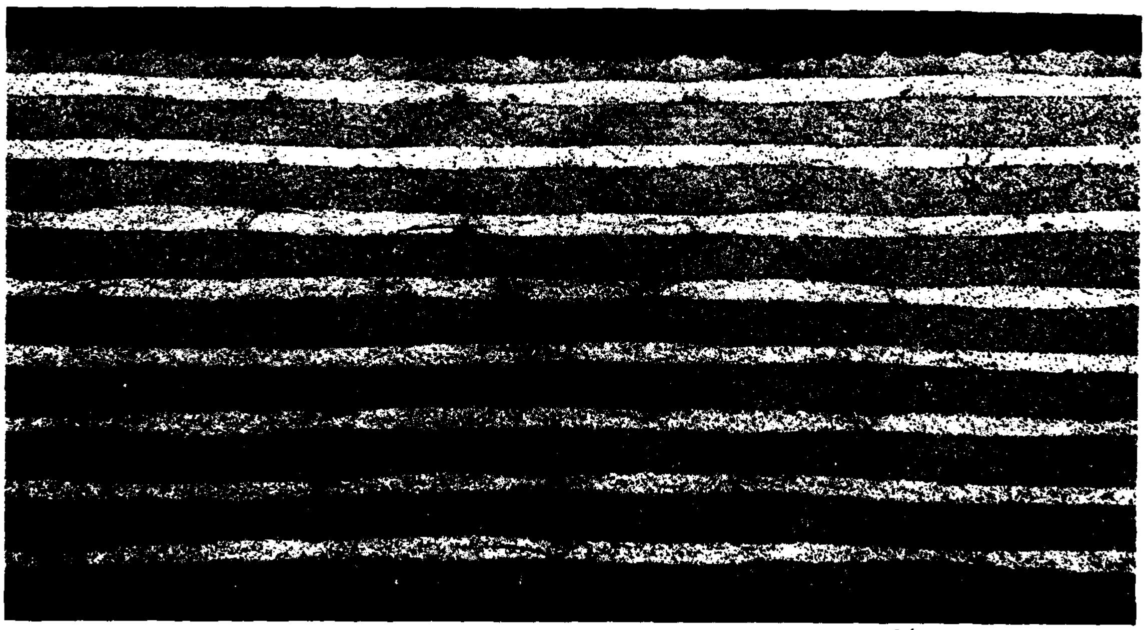
b. The volume of nitric acid used for digestion was increased from 30 cc to 100 cc because of the larger specimen size.

c. Determinations were carried out in triplicate. Specimens were taken from each end and the center of the resin sample strip which was one inch wide and extended the width of the panel.



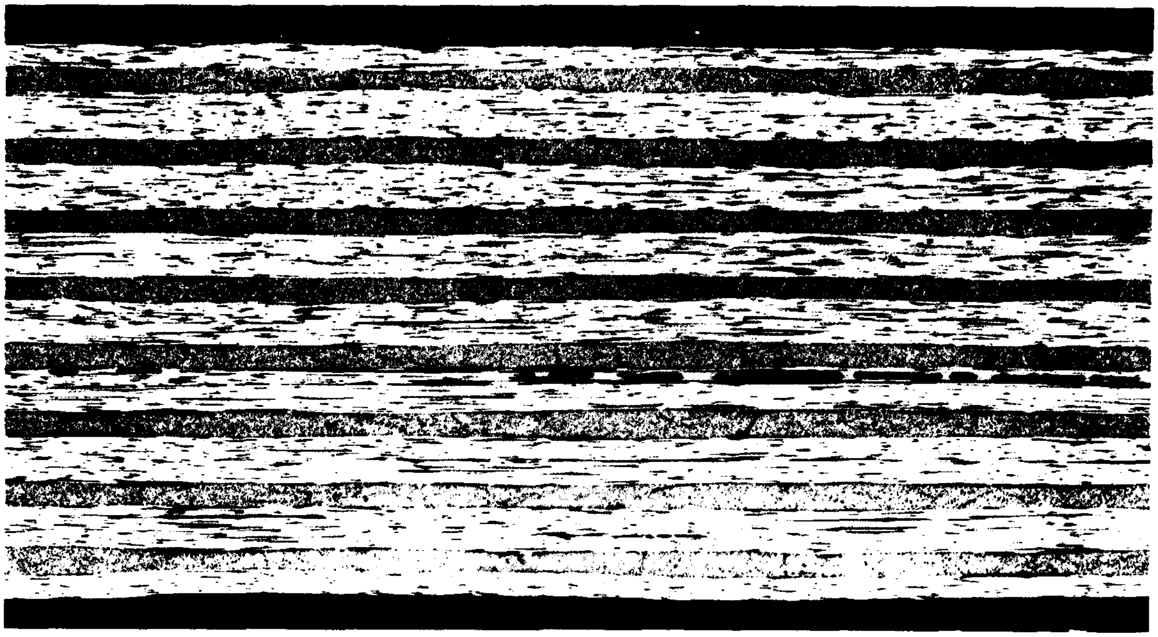
2618-1-2 100X

Figure 18. - Metallographic section of panel 1TJ1169 showing large elongated voids parallel to 0° fibers.



2617-3. 25X

Figure 19. - Metallographic section of panel 1TJ1210 at 90° to ultrasonic indications showing no voids.



2619-1 25X

Figure 20. - 0° section of panel 1TJ1210 showing voids in the 10th ply.

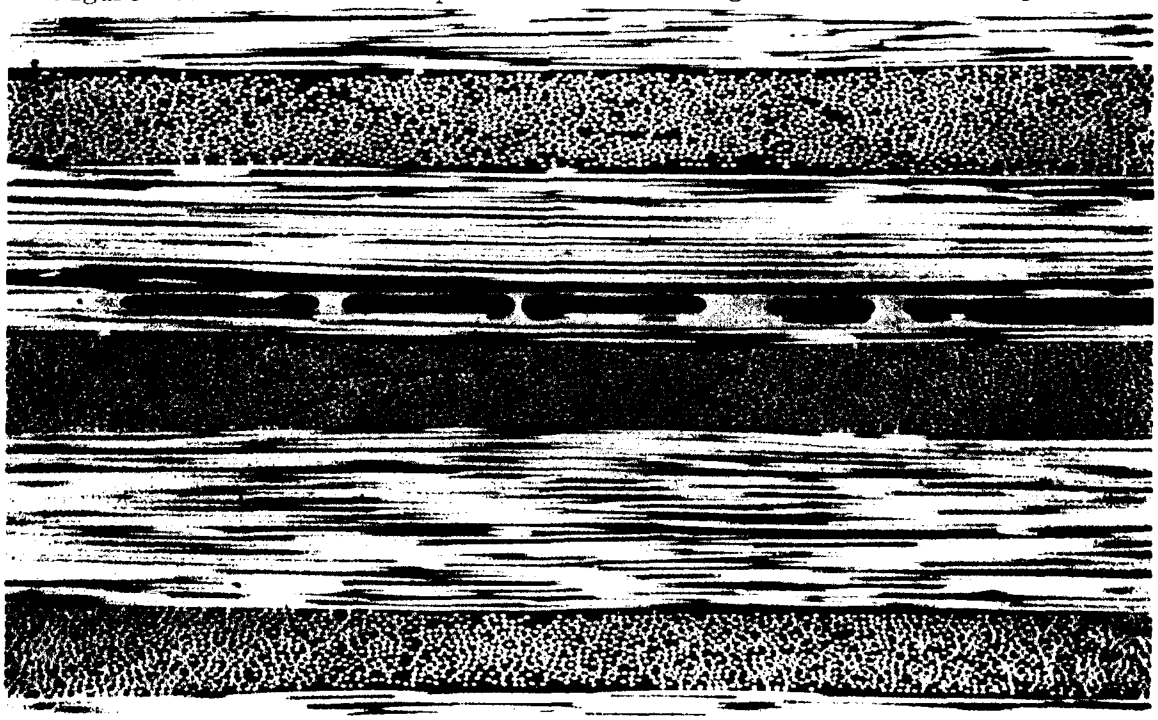


Figure 21. - Higher magnification of voids in figure 20.

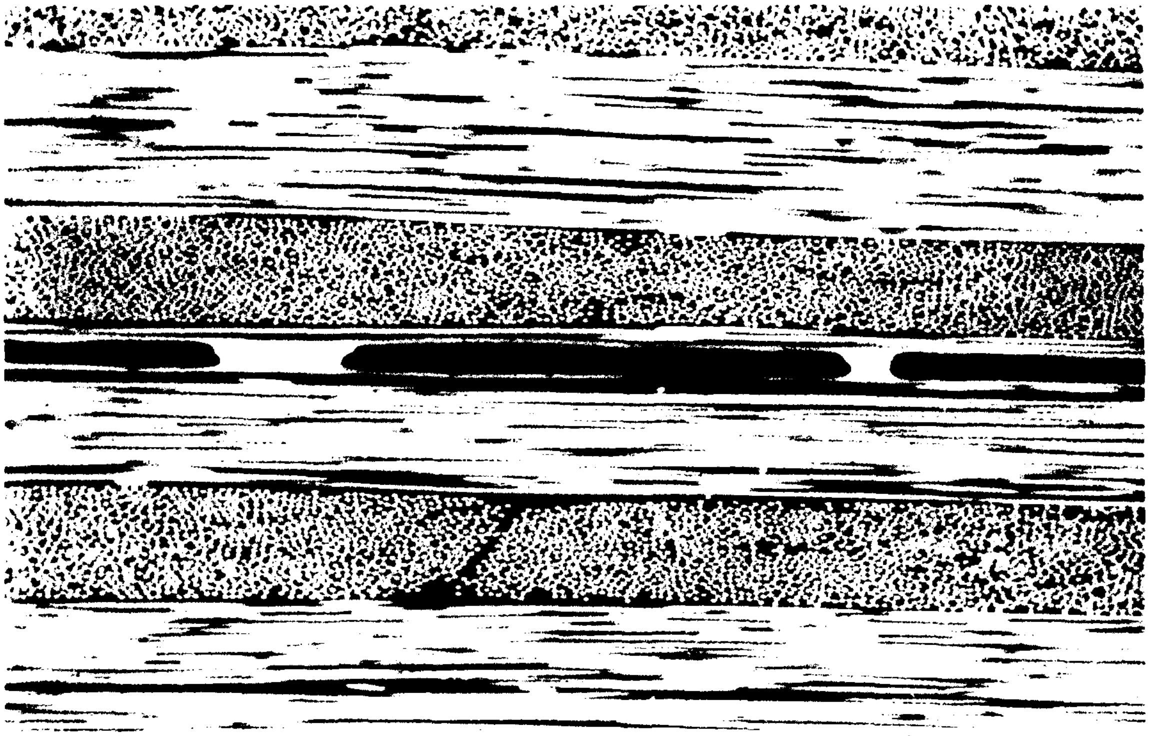


Figure 22. - 0° section of panel 1TJ1210 showing voids in 10th ply area.

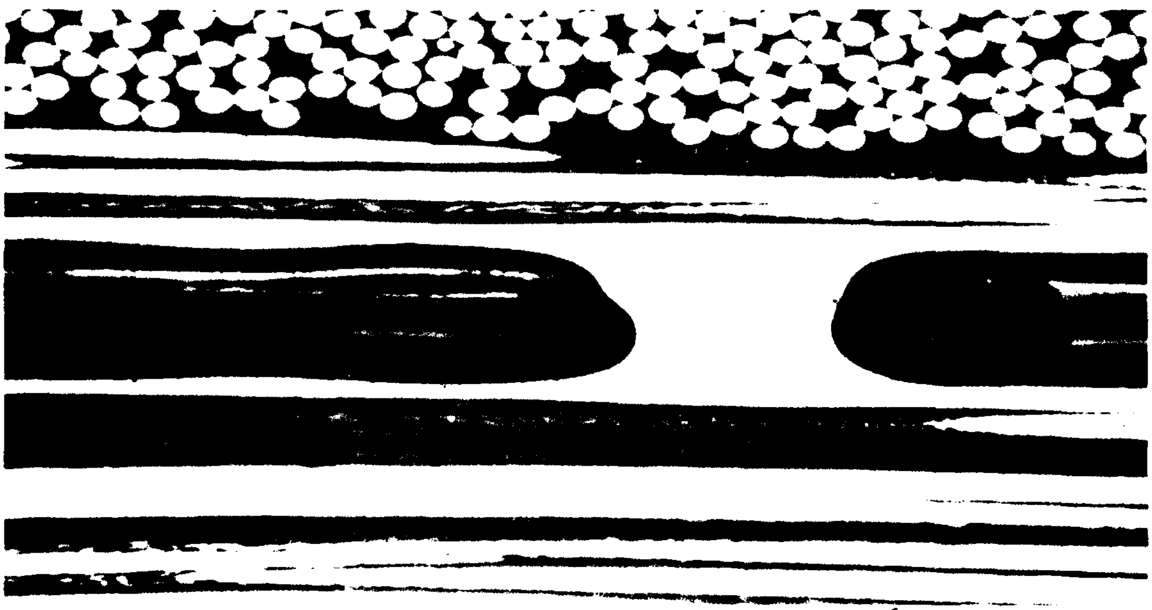
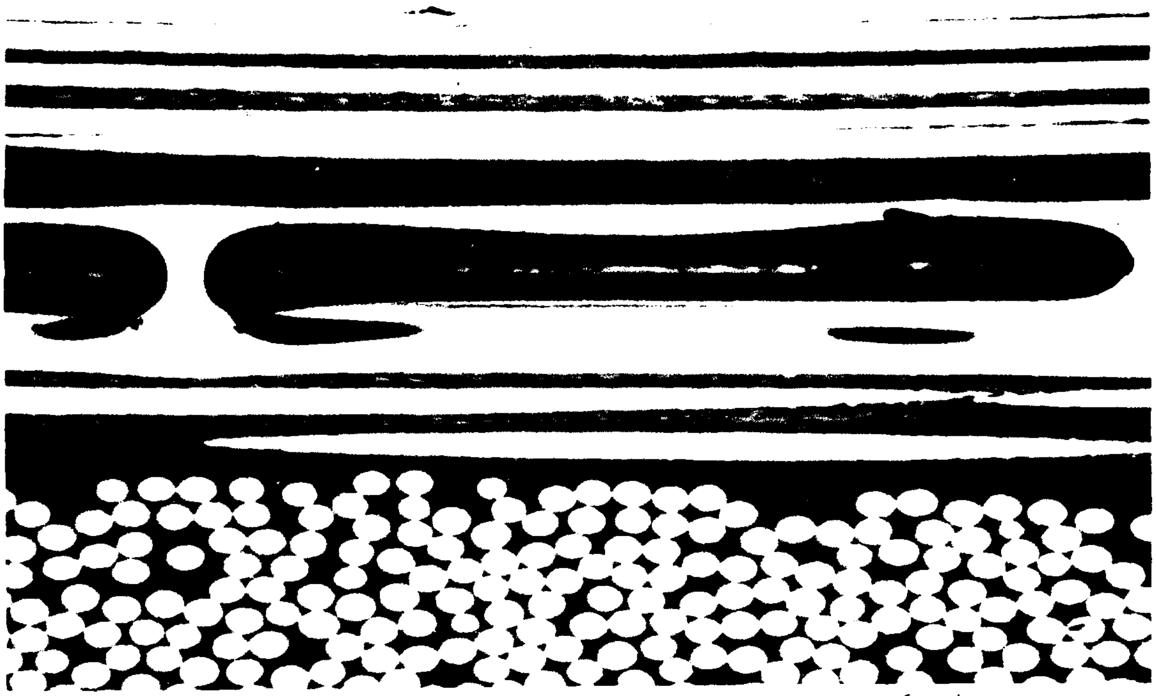


Figure 23. - Higher magnification of figure 22 showing voids in large diameter fiber. Void on left is partially filled with resin.

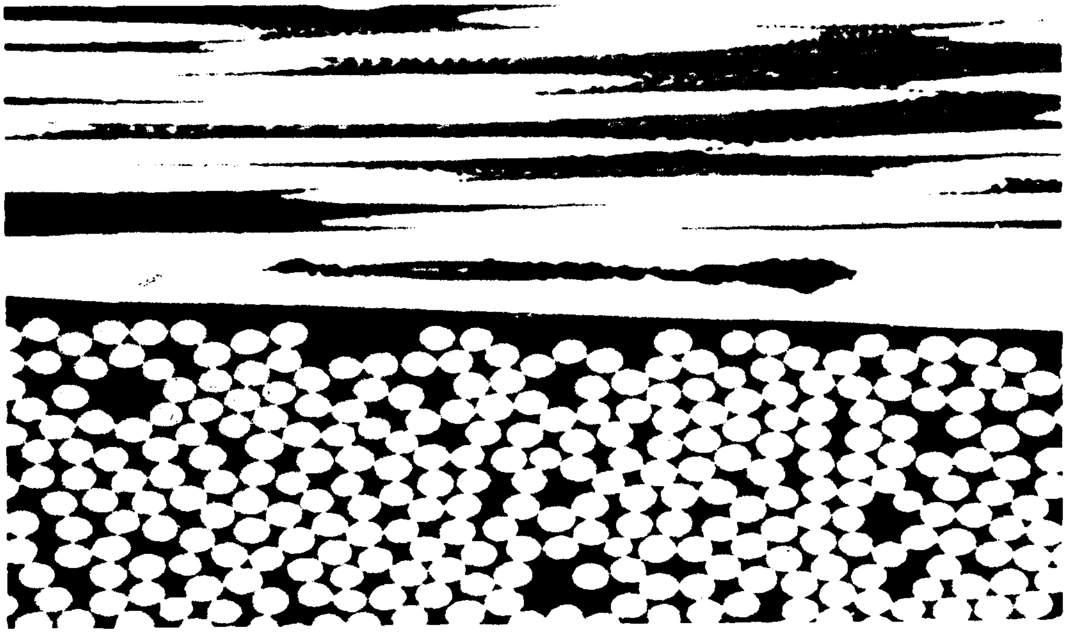


2619-4 500X

Figure 24. - Voids in large diameter fiber in 0° section of panel 1TJ1210.

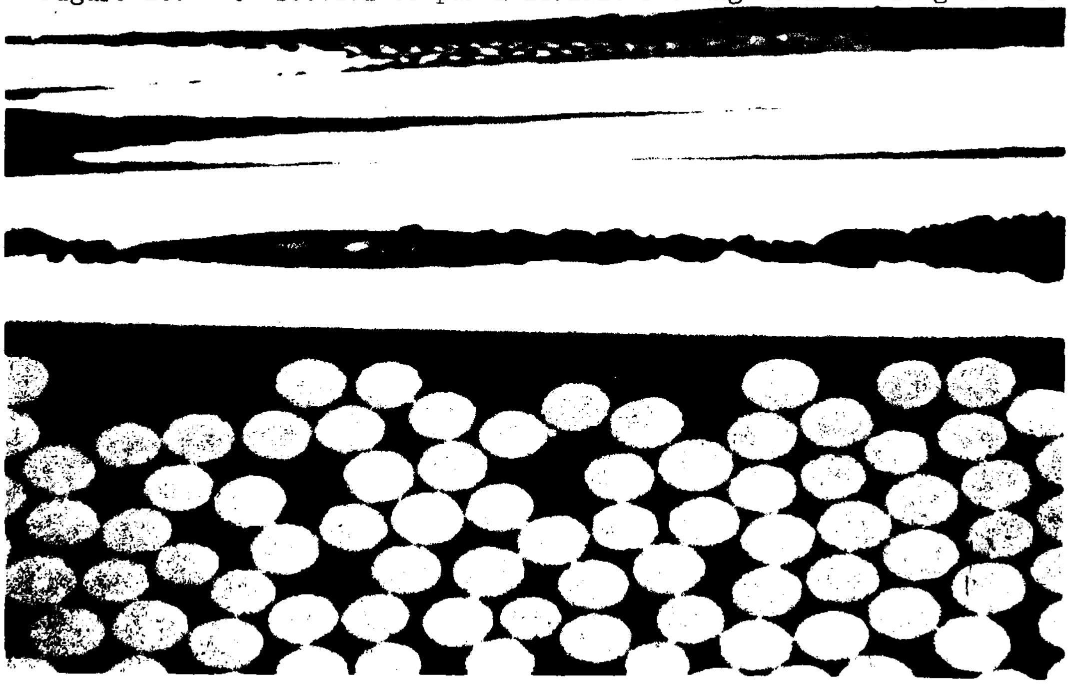
2619-7 500X

Figure 25. - Void in longitudinal section of large fiber, panel 1TJ1210.



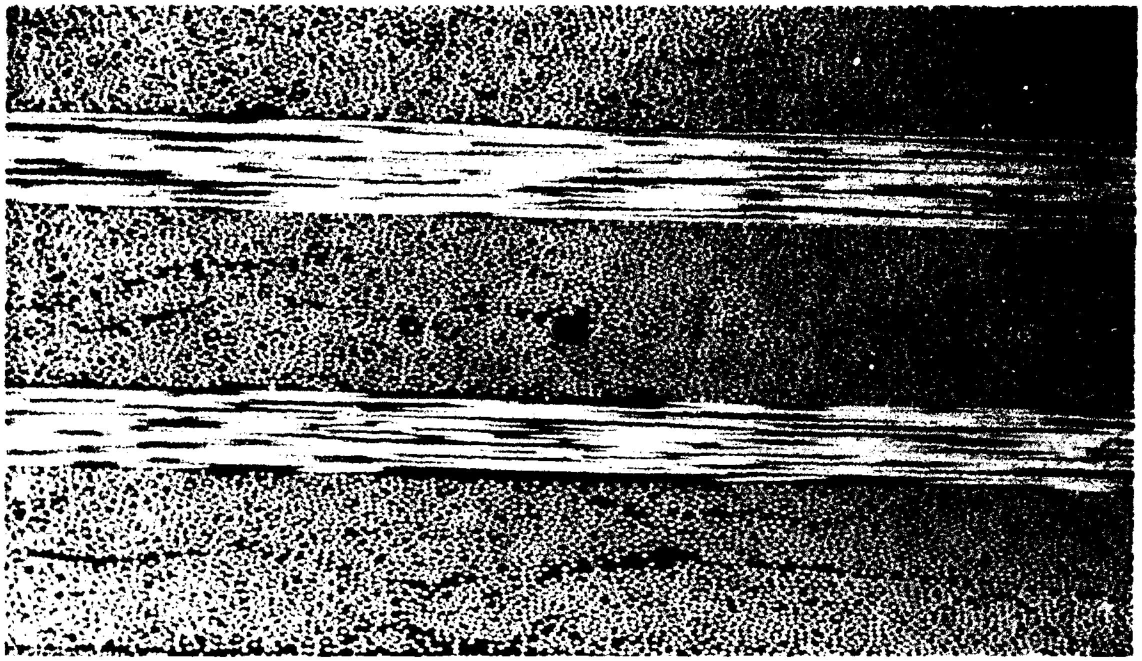
2619-8 500X

Figure 26. - 0° section of panel 1TJ1210 showing voids in large fiber.



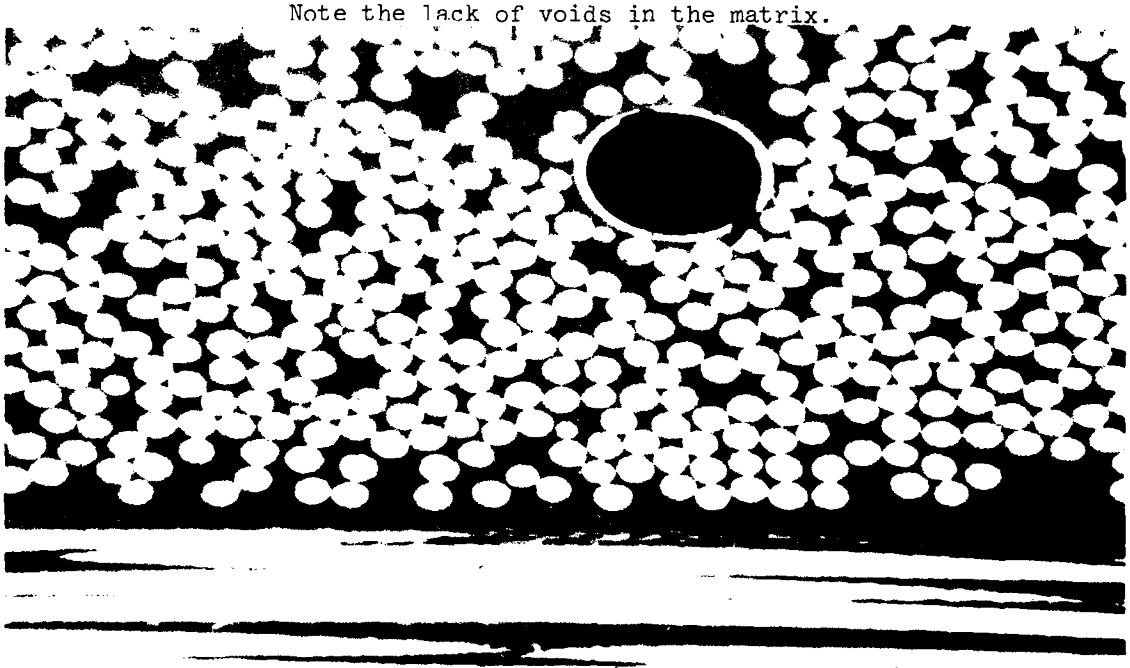
2619-6 1000X

Figure 27. - Higher magnification of figure 26.



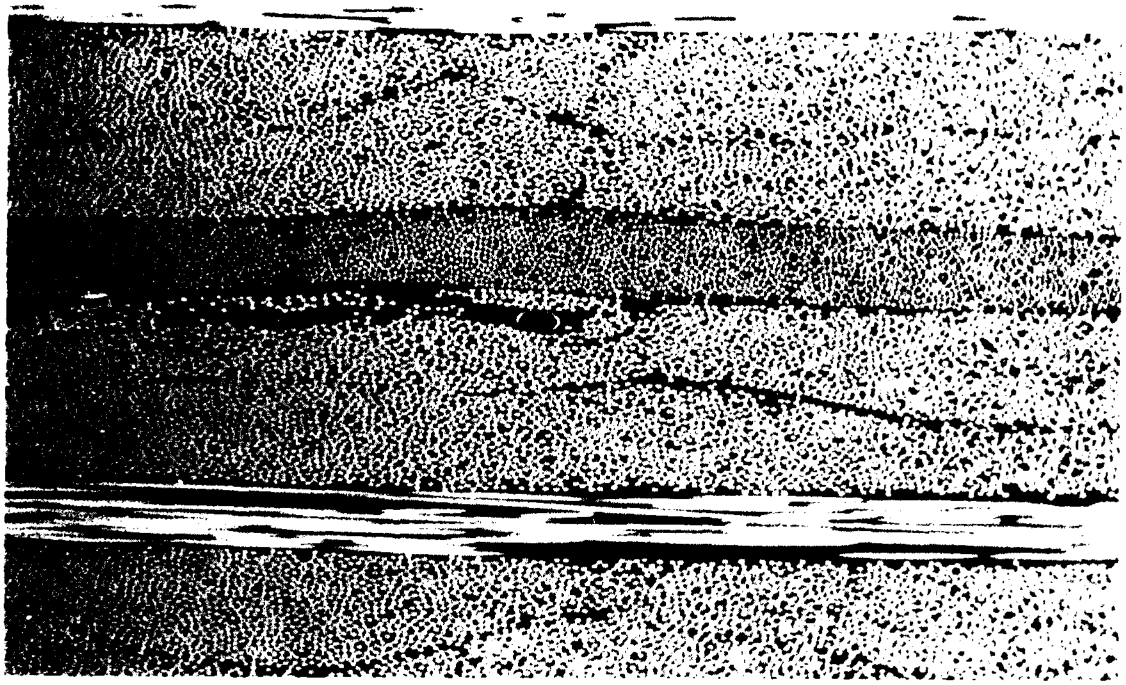
2617-1-2 100X

Figure 28. - Metallographic section at 45° to ultrasonic indications. Note the lack of voids in the matrix.



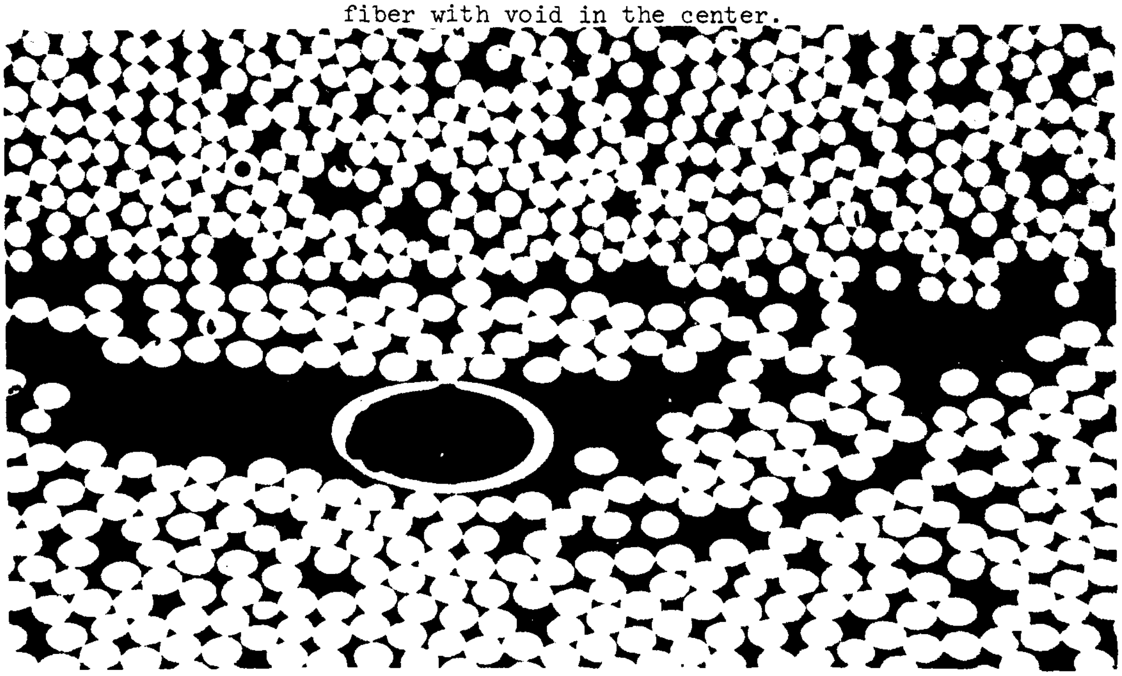
2617-1-3 500X

Figure 29. - Higher magnification of figure 28 showing the large hollow fiber.



2617-2-2 ;00X

Figure 30. - 45° section of panel 1TJ1210 showing large fiber with void in the center.

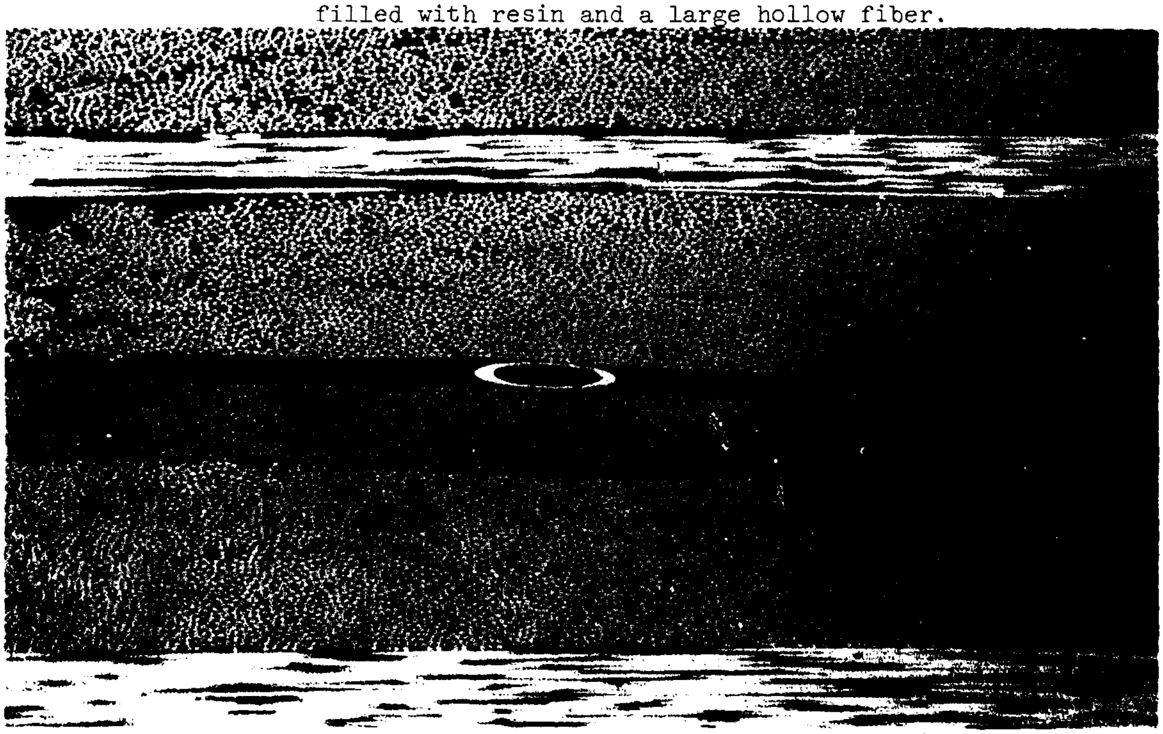


2617-2-4 500 X

Figure 31. - Higher magnification of figure 30.

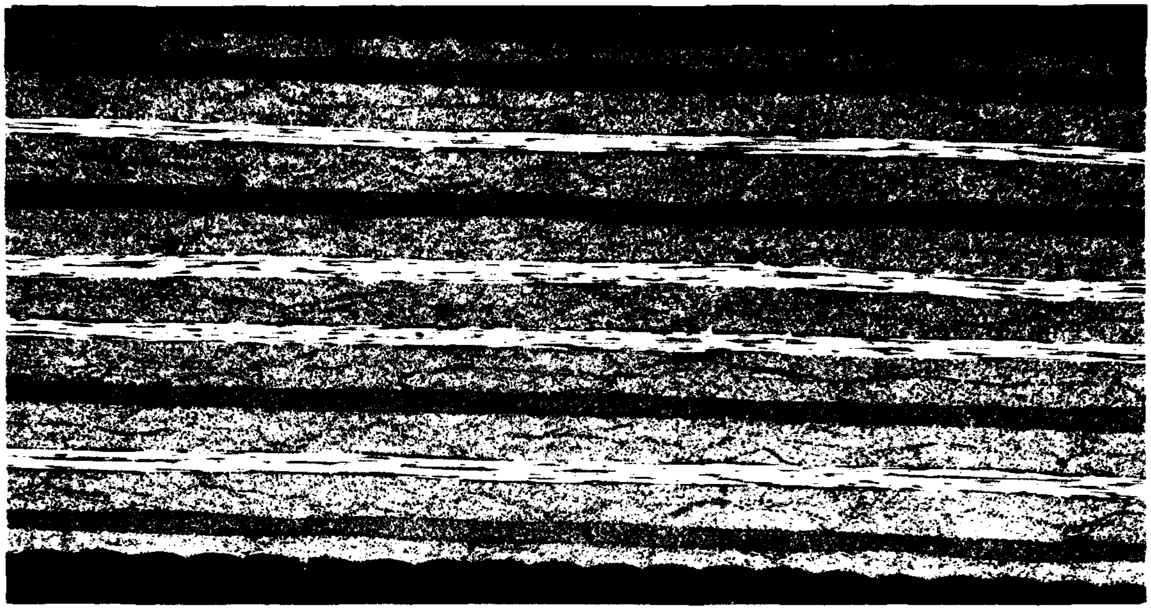
2617-2 25X

Figure 32. - 45° section of panel 1TJ1210 showing a large fiber filled with resin and a large hollow fiber.



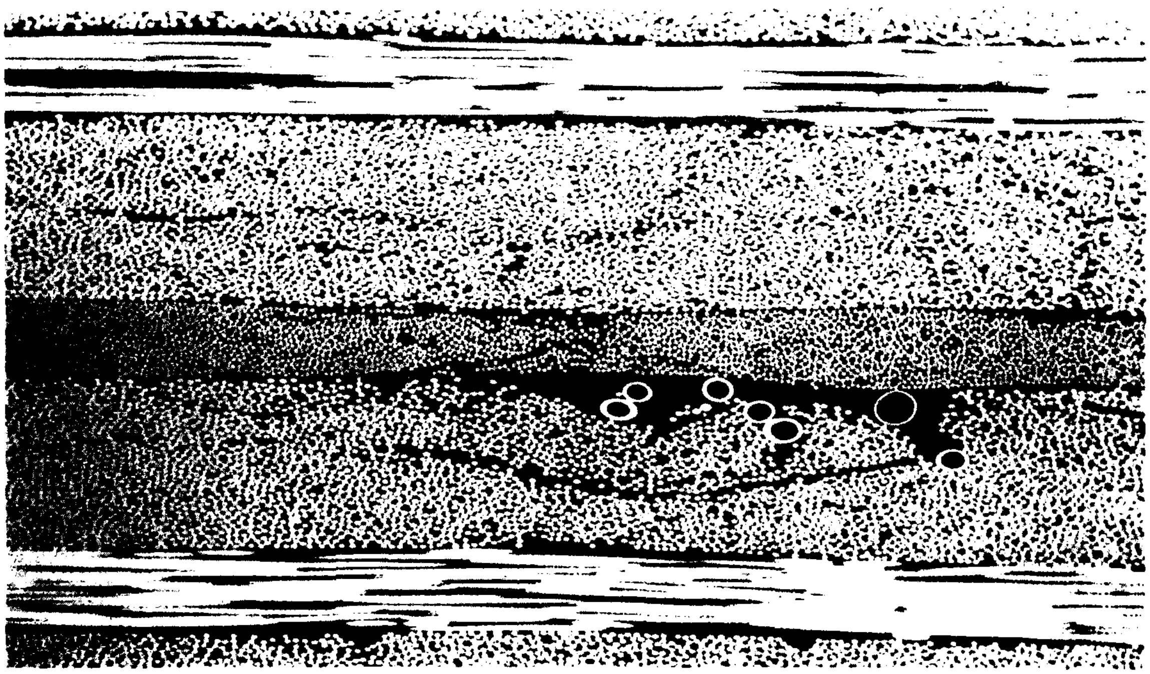
2617-2-3 100X

Figure 33. - Higher magnification of filler fiber shown above. Note the large resin area surrounding the fiber.



2617-1 25X

Figure 34. - 45° section of panel 1TJ1210 showing void in matrix between 12th and 13th plies.



2617-1-1 100X

Figure 35. - 45° section of panel 1TJ1210 showing a grouping of seven large resin filled fibers.

TABLE 8

FIBER PROPERTIES REPORTED BY MANUFACTURER

	Fiber Lot No.	Fiber Density g/cc	Fiber Tensile Strength MPa (ksi)	Fiber Modulus GPa (psi x 10^6)
T300/ 5208 BATCH TY	434-2	1.738	3089 (448)	228 (33.0)
	425-2	1.730	3034 (440)	230 (33.4)
	433-2	1.747	3006 (436)	232 (33.6)
T300/ 5208 BATCH SY	368-2	1.709	2882 (418)	225 (32.7)
	369-2	1.748	2868 (416)	225 (32.6)
	378-2	1.724	2806 (407)	227 (32.9)
	379-2	1.716	2799 (406)	228 (33.0)
AS/3501-5A BATCH TJ	N/A	1.818	3178 (461)	231 (33.5)

TABLE 9

RESIN, FIBER, AND VOID ANALYSIS RESULTS

T300/5208 BATCH TY

Panel No.	Laminate Type	Resin Content Wt.%	Fiber Content Vol.%	Void Content Vol.%	Density g/cc
2TY 1218	L1	26.48	67.06	-0.2	1.585
1TY 1224	L1	27.64	65.74	-0.2	1.579
1TY 1226	L1	26.77	66.62	-0.0	1.581
1TY 1225	L2	27.03	66.28	-0.0	1.579
2TY 1225	L2	27.12	66.28	-0.2	1.581
2TY 1226	L2	27.48	66.31	-0.2	1.580
1TY 1216	U1	26.45	67.16	-0.3	1.587
2TY 1216	U1	26.29	67.30	-0.3	1.588
1TY 1218	U1	24.90	68.85	-0.2	1.593
1TY 1227	U2	26.38	67.10	-0.1	1.584
	Average	26.65	66.87		1.584
	Std. Dev.	0.77	0.86		0.0046
	Coef. of Var. %	2.89	1.29		0.29

TABLE 10

RESIN, FIBER, AND VOID ANALYSIS RESULTS

T300/5208 BATCH SY

Panel No.	Laminate Type	Resin Content Wt.%	Fiber Content Vol.%	Void Content Vol.%	Density g/cc
ISY 1424	L1	27.39	66.45	-0.2	1.578
ZSY 1424	L1	26.91	67.02	-0.3	1.581
ISY 1423	L2	29.70	63.87	-0.2	1.566
ZSY 1423	L2	28.86	64.79	-0.2	1.570
	Average	28.22	65.53		1.574
	Std. Dev.	1.29	1.46		0.0069
	Coef. of Var. %	4.58	2.22		0.44

TABLE 11

RESIN, FIBER, AND VOID ANALYSIS RESULTS

AS/3501-5A BATCH TJ

Panel No.	Laminate Type	Resin Content Wt.%	Fiber Content Vol.%	Void Content Vol.%	Density g/cc
1TJ 1282	L1	28.93	63.13	-0.1	1.616
1TJ 1240	L2	28.31	63.99	-0.2	1.624
1TJ 1245	L2	28.91	63.32	-0.2	1.620
1TJ 1283	L2	29.24	62.80	0.0	1.614
2TJ 1283	L2	29.51	62.54	-0.1	1.614
2TJ 1281	U1	27.53	64.76	-0.0	1.626
1TJ 1281	U2	28.65	63.51	-0.0	1.619
	Average	28.72	63.44		1.619
	Std. Dev.	0.65	0.75		0.0047
	Coef. of Var. %	2.28	1.18		0.29

Density was determined in accordance with ANSI/ASTM D792-66, Procedure A-1: "Specific Gravity and Density of Plastics by Displacement".

Void contents were calculated by the method described in ASTM D2734-70: "Void Content of Reinforced Plastics" except as noted below:

a. Fiber volume was measured according to ASTM D3171 not D2584

b. Fiber density was supplied by the manufacturer.

c. Resin density was supplied by the manufacturer.

This method is highly dependent on the size and distribution of voids and on accurate values for fiber and resin densities. Large non-uniform void distributions can cause considerable variations. Neat resin density is usually higher than that in the composite tending to make the void content sum lower. Absorbed moisture also affects the density. These facts coupled with the uncertainty of the original fiber and matrix properties lead to errors of approximately ±1.6% in void content, and can thus result in negative void content values. But, these low void contents in conjunction with the lack of C-scan indications imply that the void content of all panels is extremely low. However, panel cross sections were examined by optical microscopy at 1000X as additional verification, and essentially no voids were apparent.

4. EXPERIMENTAL RESULTS

4.1 Thermal Expansion Measurements

Linear thermal expansion measurements were performed using tube type dilatometers. A vitreous silica dilatometer, constructed and operated in accordance with ASTM E228-66aT, was employed to cover the temperature range of -54°C (-65°F) to 135°C (275°F).

The pushrod-type of dilatometer measures the difference in length change between the sample and a reference material which forms the sample support means (outer tube). Thus, the thermal expansion characteristics and temperature of the reference material, over the sample length, must be accurately known. Vitreous silica is a very stable low thermal expansion material for temperatures to 927°C (1700°F) and is used extensively in dilatometric measurements.

Linear thermal expansion is defined as the change in length per unit length with a change in material temperature. This is expressed as $\Delta L/L_o$ where ΔL is the observed change in length of the specimen and L_o is the specimen length at a reference temperature, 19°C (67°F) for the testing discussed herein. The thermal expansion coefficient is:

$$\left(\frac{dL}{dT}\right) \frac{1}{L_o}$$

All testing was conducted at atmospheric pressure. Tests from -157°C (-250°F) to 927°C (1700°F) are conducted in a dry helium atmosphere. For the low-temperature dilatometer system, the vitreous silica outer tube and pushrod assembly are suspended in a silica tube which is immersed in a cryogen dewar. A copper sheath with heater windings is located between the specimen and outer tubes for control of sample temperature. Sample space is filled with helium

and the outer chamber is evacuated during operation. The motion of the pushrod is measred with a piezoelectric transducer having a sensitivity of 2.5×10^{-5} mm (1×10^{-6} in.). The heater is controlled to heat the specimen at $1^{\circ}C$ ($2^{\circ}F$) per min. by a proportional type controller having a continuously variable set point input and a 2-kW SCR power supply.

The pushrod assembly is suspended from an Invar bracket which serves as the mounting for the transducer, which measures pushrod motion. This transducer has full-scale ranges of 5.1×10^{-2} mm (2×10^{-3} in.) and 0.25 mm (1×10^{-2} in.) with a sensitivity of 2.5×10^{-5} mm (1×10^{-6} in.). The transducer control unit output signal is recorded continuously together with the specimen thermocouple output with an x-y plotter.

Sample preparation consists of cutting each bar to a nominal length of 76 mm (3 in.), 229 mm (9 in.) or 305 mm (12 in.); finishing the ends so that they are flat and parallel; measuring length, diameter, and weight of specimen; and installation of the appropriate thermocouple in the center of each bar, the junction being cemented to the specimen with a small bead of refractory cement. Post-test measurements are made of specimen overall length and diameter.

Thermal expansion, $\Delta L/L_o$, is calculated from the recorded dimensional change, ΔL (from dial gage or from transducer output voltage times calibration factor of mils per volt), and the dimensional change of the dilatometer over the specimen length by the following:

$$\Delta L/L_o = \Delta L_g/L_o + \Delta L_d/L_o$$

where L_o is the initial specimen length, ΔL is the pushrod motion, and ΔL_d is the dilatometer expansion from calibration data.

Thermal expansion measurements were performed in the longitudinal and transverse directions for the three laminates (U1, L1, L2) of each material. Results are presented in Figures 36 through 47.

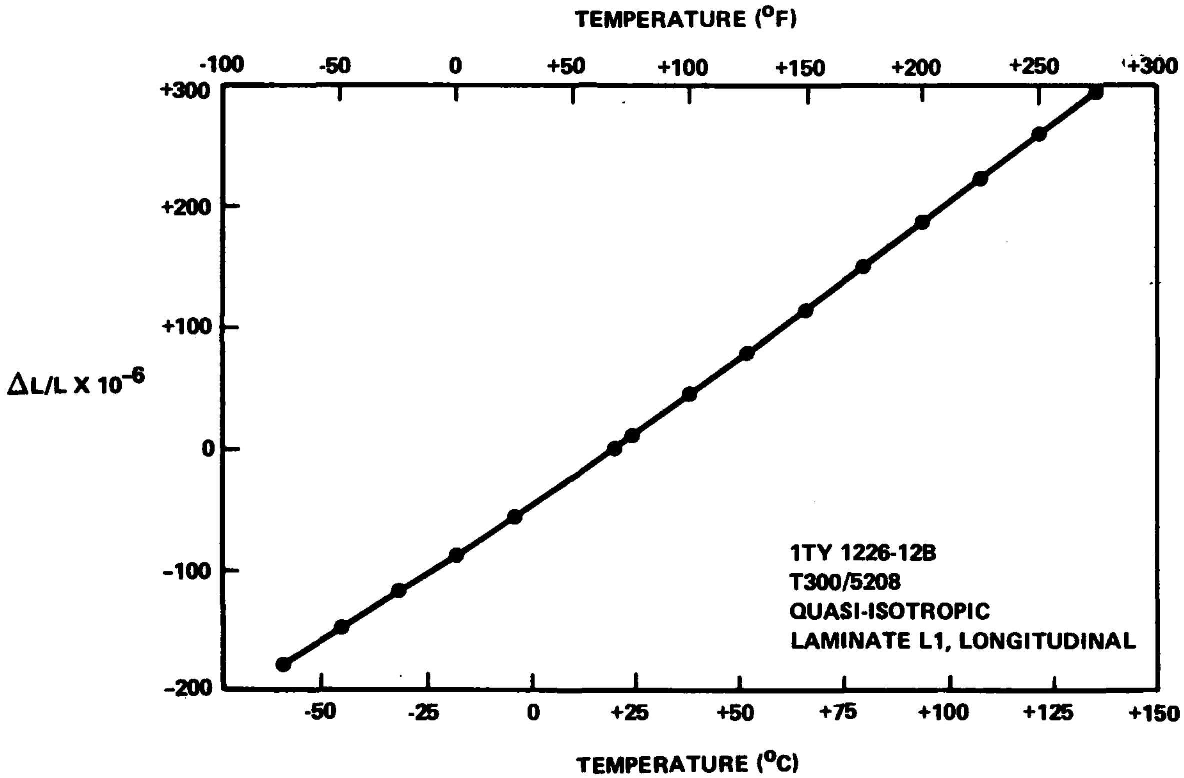


Figure 36. - Thermal expansion characteristics of T300/5208 laminate L1L.

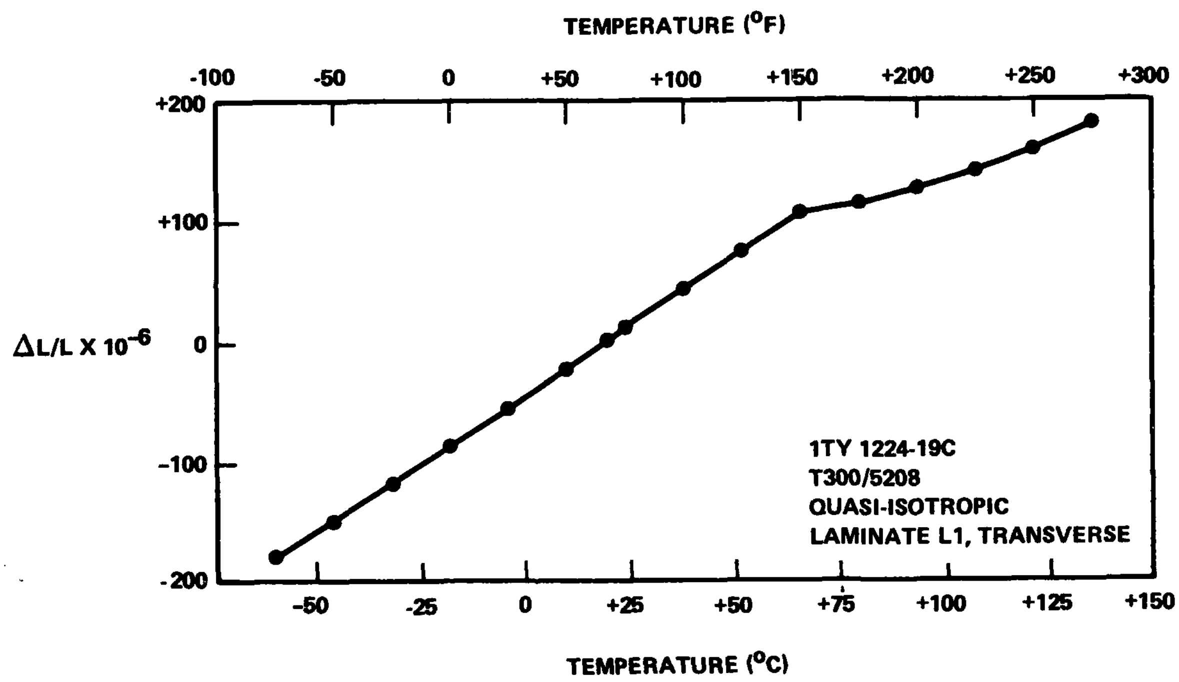


Figure 37. - Thermal expansion characteristics of T300/5208 laminate L1T.

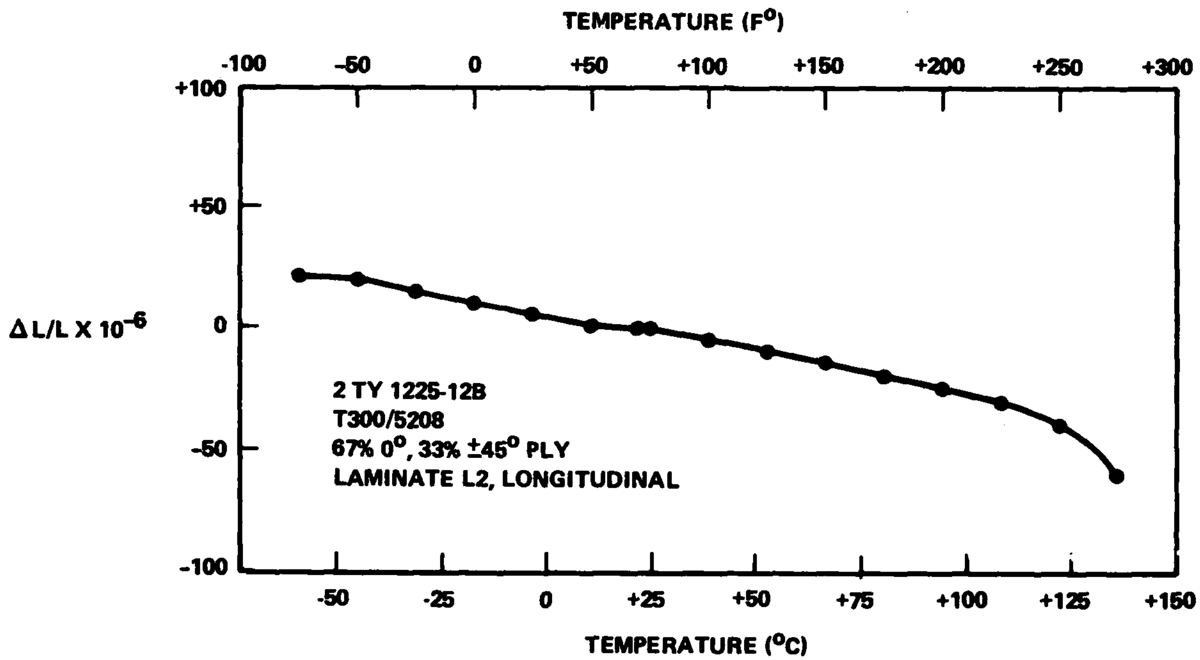


Figure 38. - Thermal expansion characteristics of T300/5208 laminate L2L.

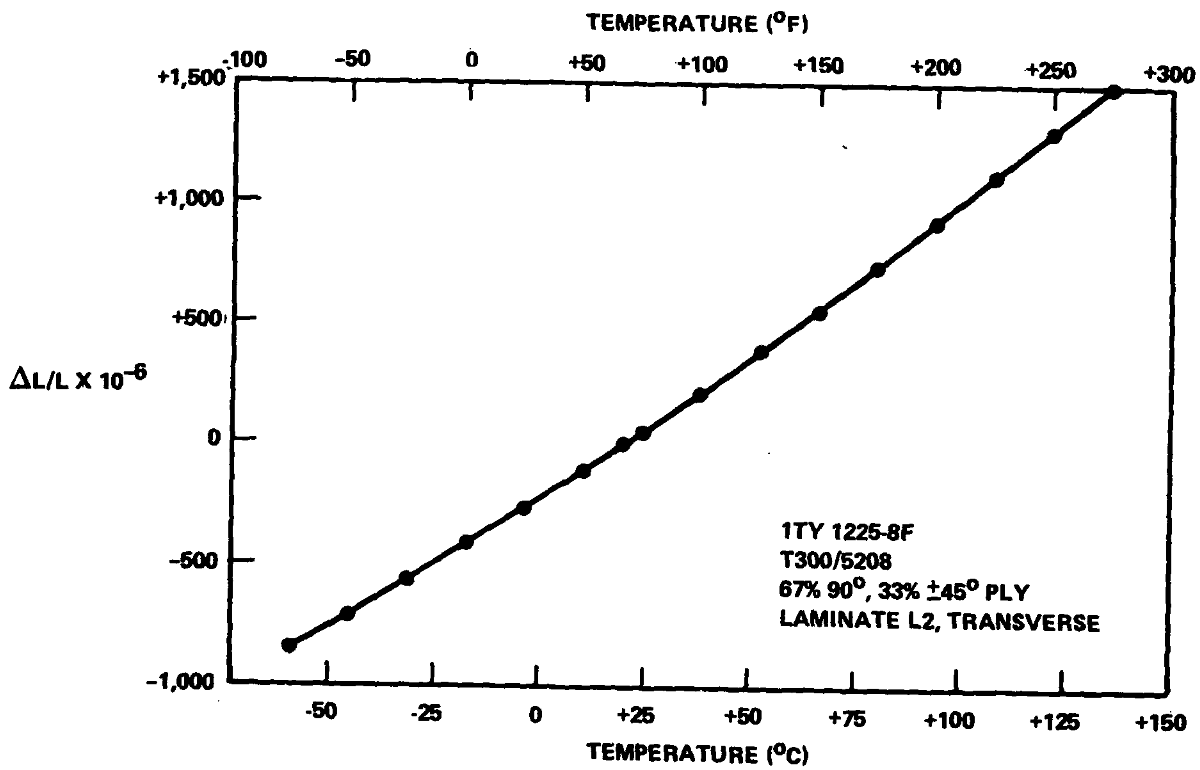


Figure 39. - Thermal expansion characteristics of T300/5208 laminate L2T.

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THE EFFECT OF ENVIRONMENT ON THE COMPRESSIVE STRENGTHS OF LAMIN--ETC(U)
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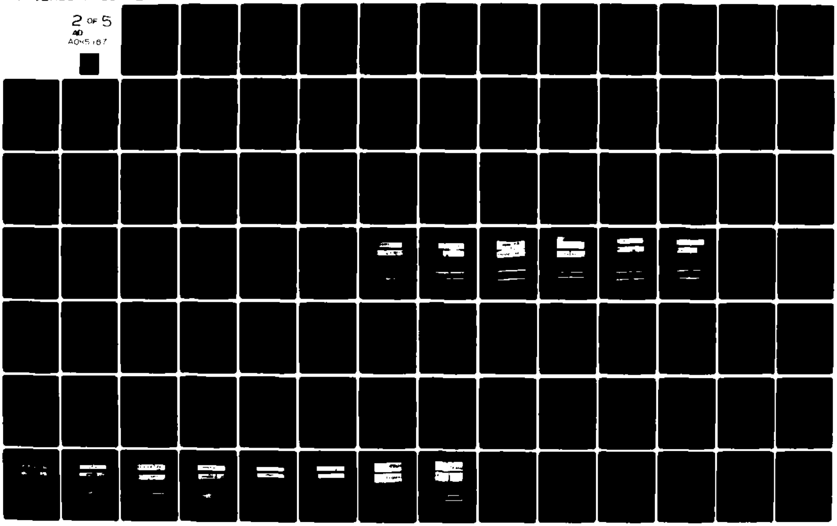

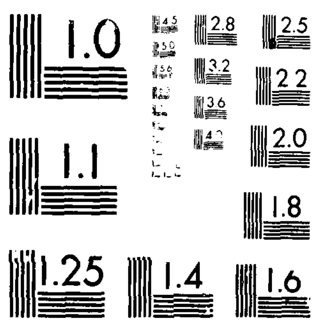

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

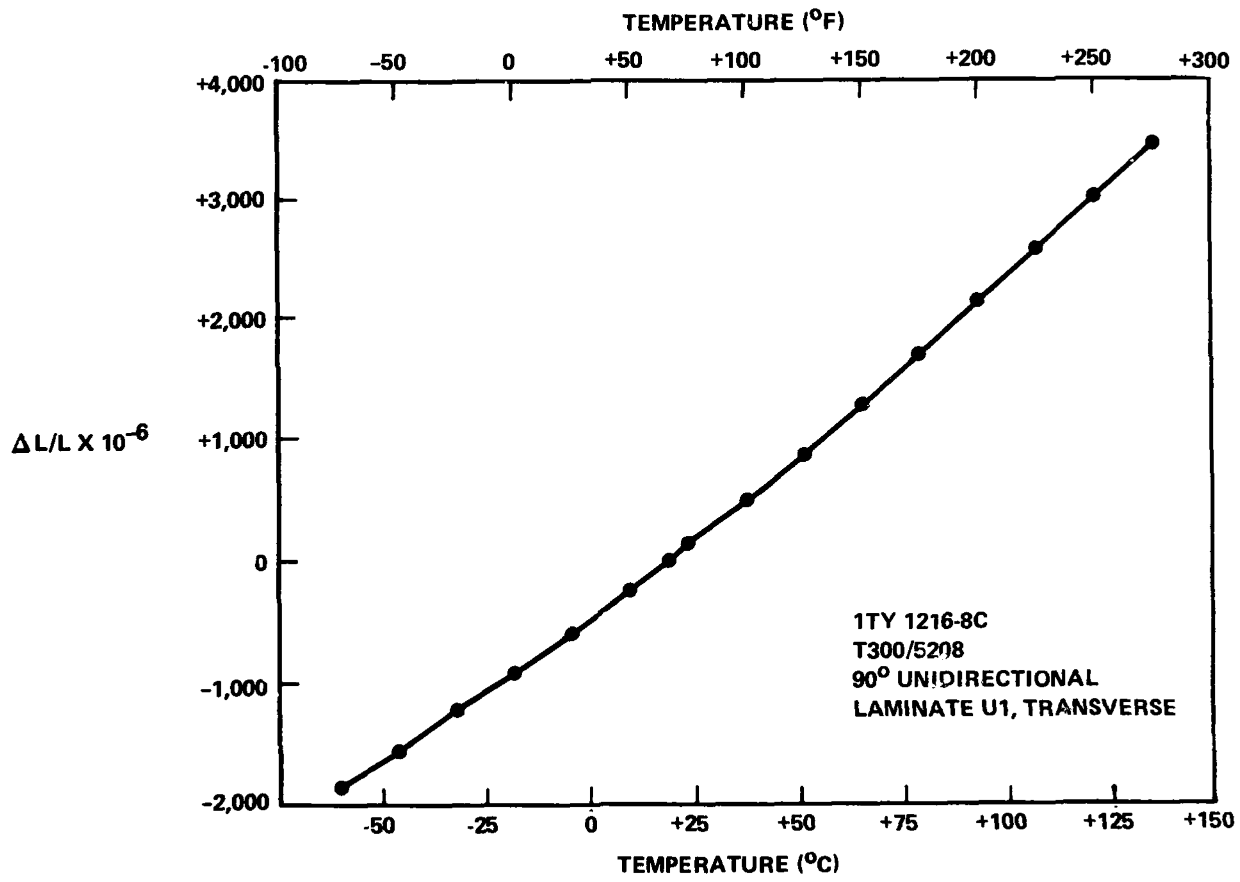

Figure 41. - Thermal expansion characteristics of T300/5208 laminate U1T.

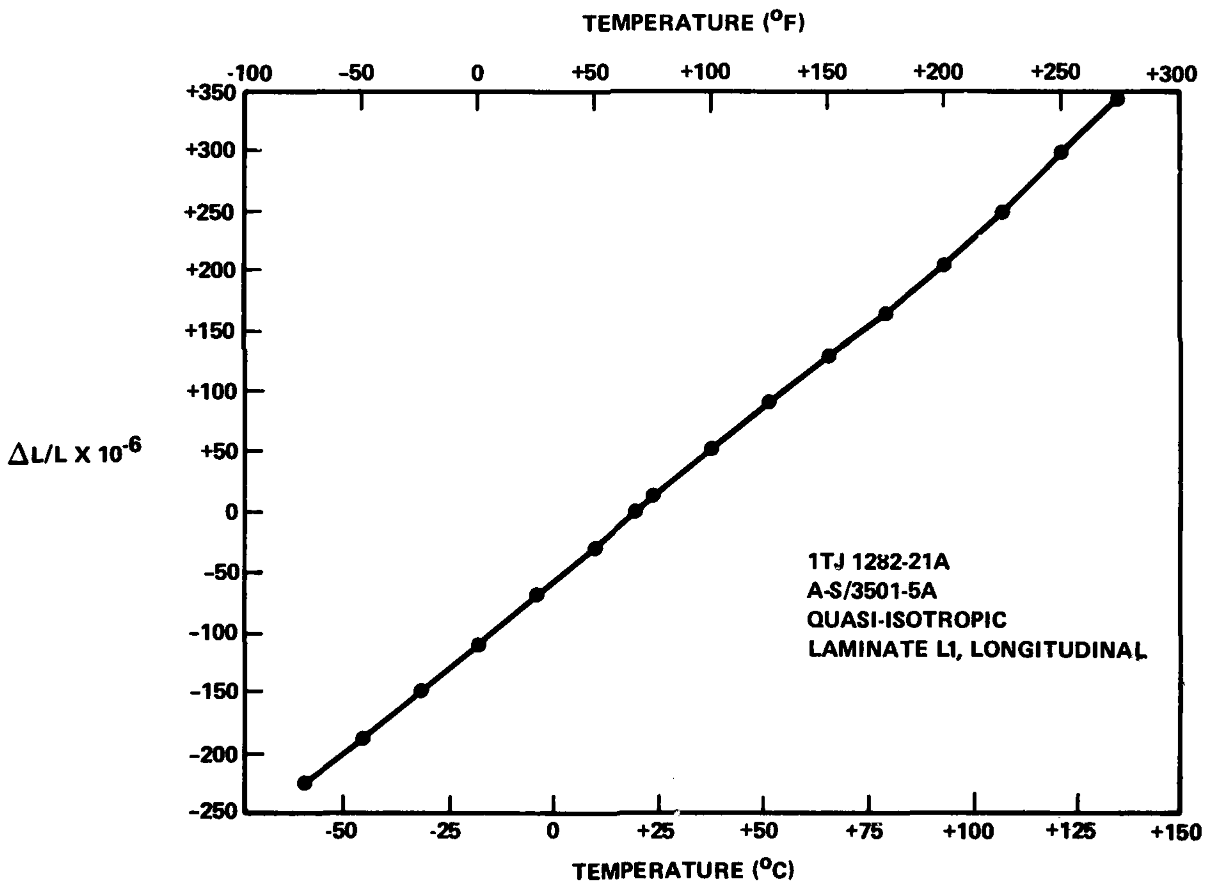

Figure 42. - Thermal expansion characteristics of AS/3501-5A laminate L1L.

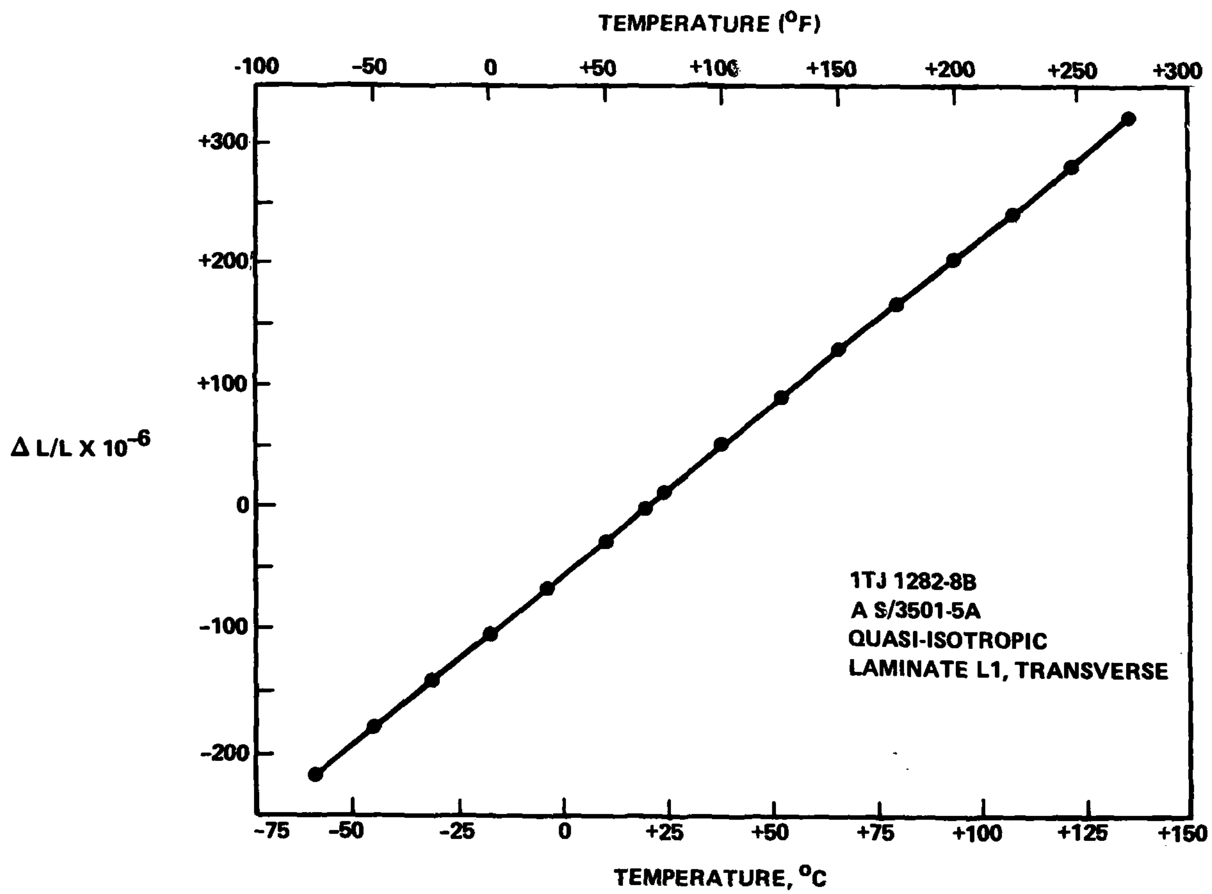

Figure 43. - Thermal expansion characteristics of AS/3501-5A laminate L1T.

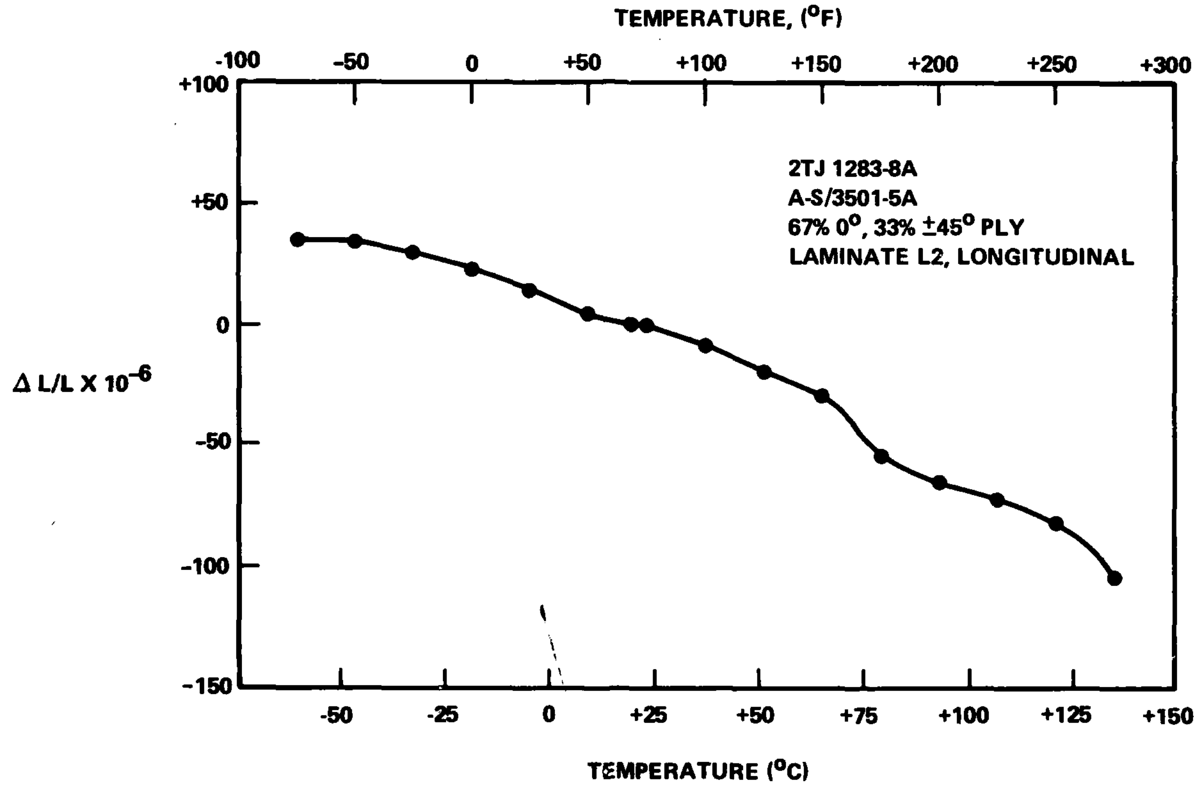

Figure 44. - Thermal expansion characteristics of AS/3501-5A laminate L2L.

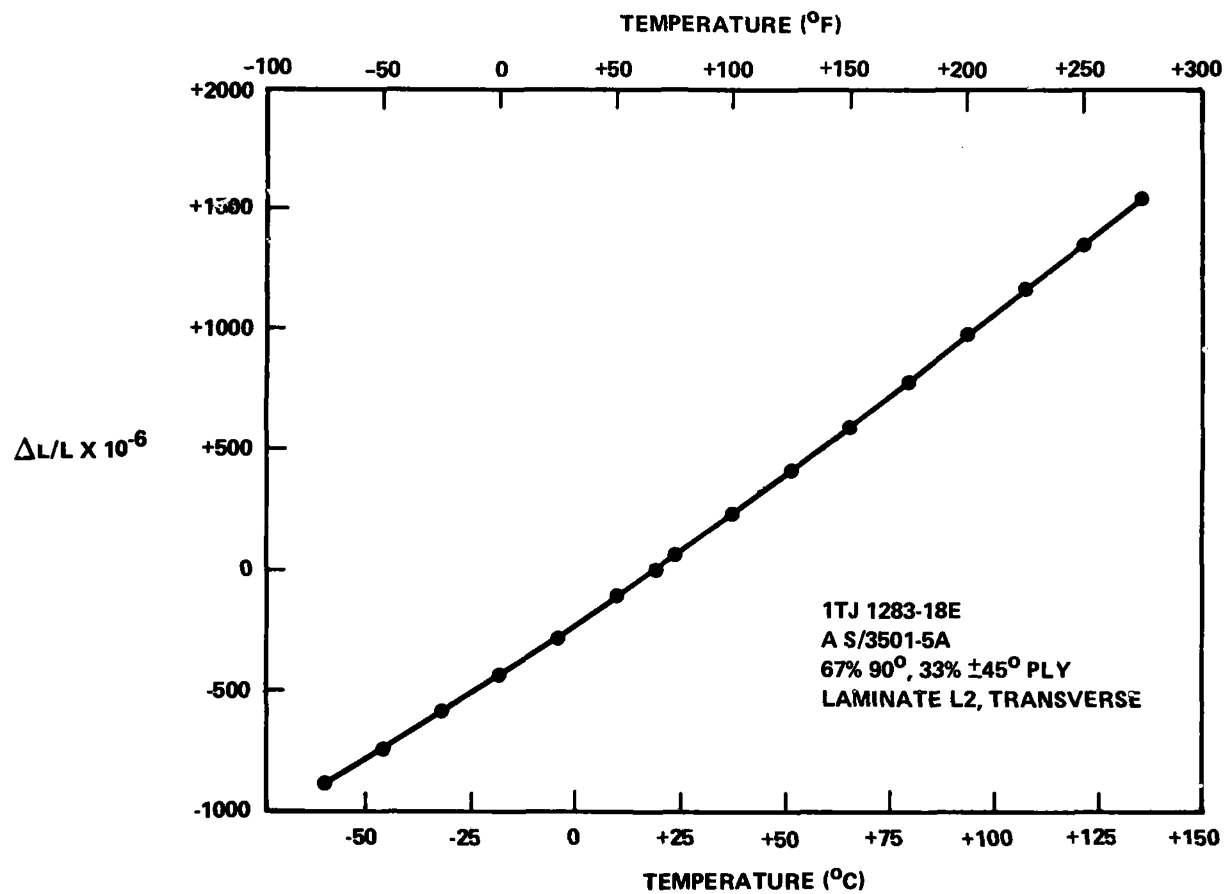

Figure 45. - Thermal expansion characteristics of AS/3501-5A laminate L2T.

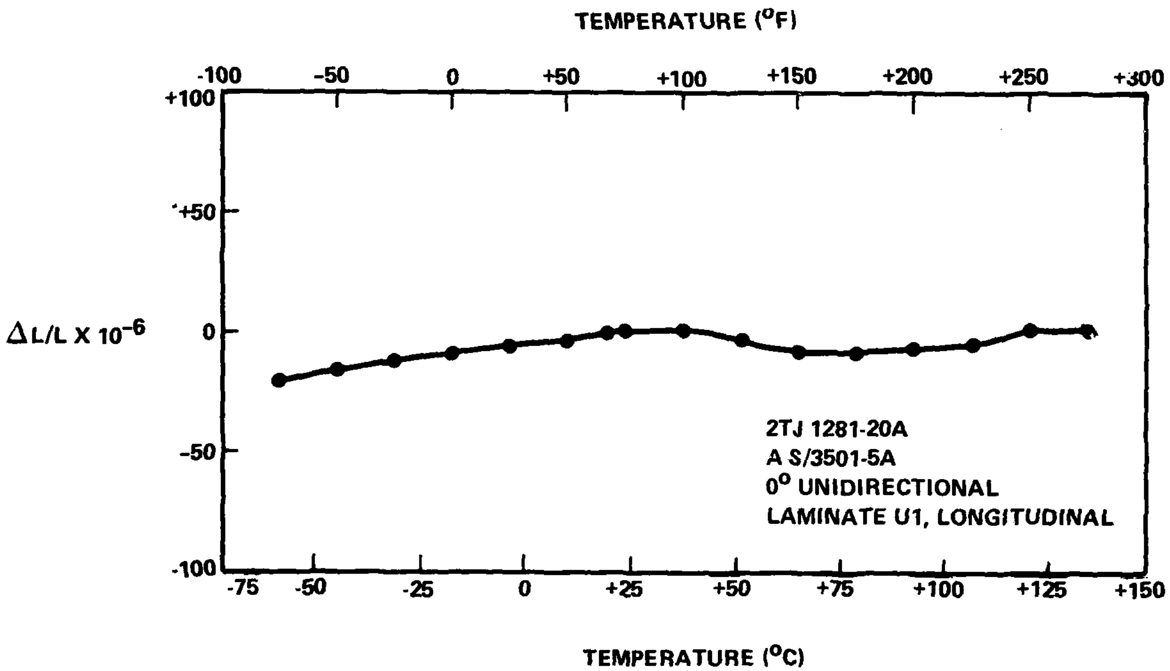

Figure 46. - Thermal expansion characteristics of AS/3501-5A laminate U1L.

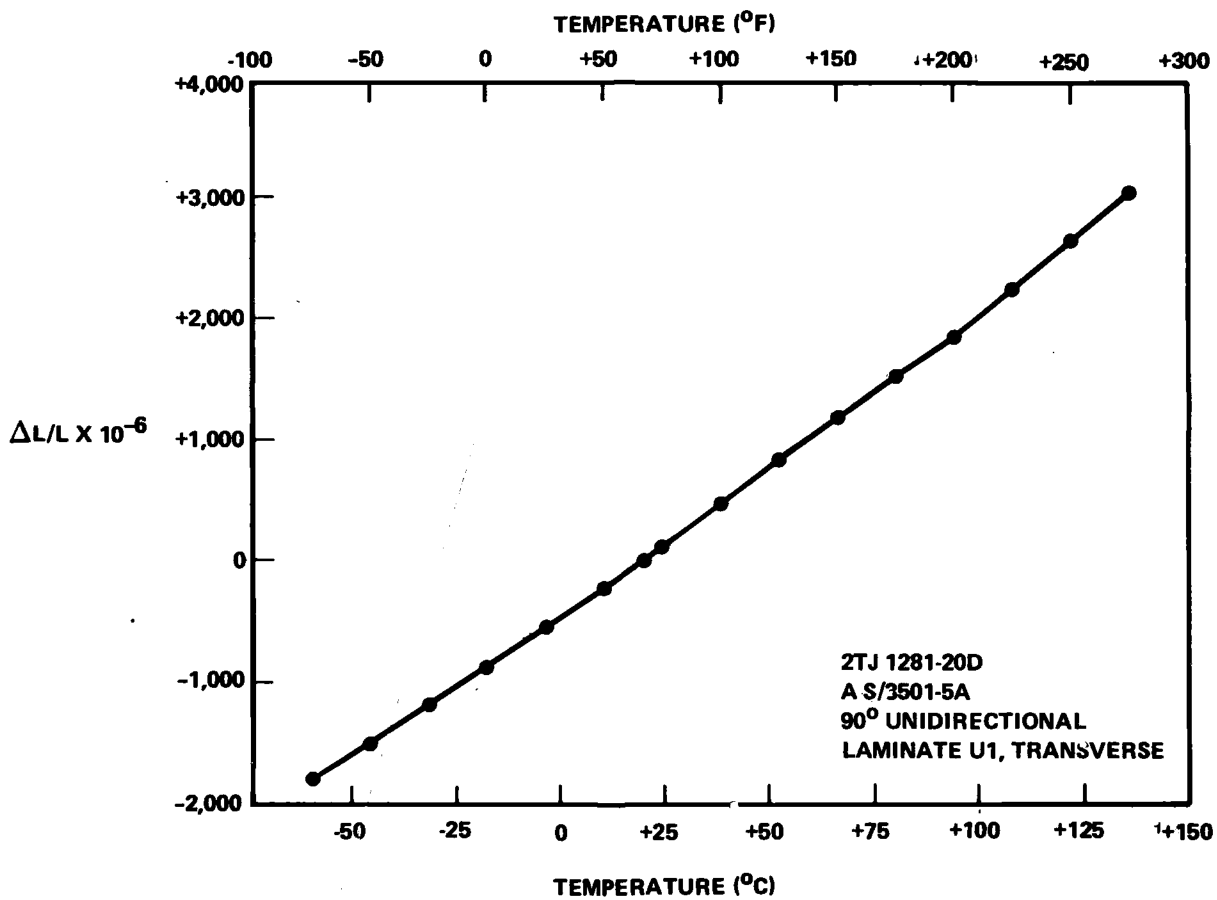

Figure 47. - Thermal expansion characteristics of AS/3501-5A laminate U1T.

4.2 Determination of the Glass Temperature, T_g

The glass temperature, T_g (also called the glass transition temperature) was measured using the Du Pont Model 900 Differential Thermal Analyzer and the ancillary Model 941 Thermomechanical Analyzer (TMA). In this combination, the Model 900 is the control and output unit for the Model 941 TMA.

The instrument can be operated in the expansion mode or penetration mode. In the expansion mode, either the linear expansion or the volumetric expansion (dilatometry) of the test specimen is measured as a function of programmed temperature. In the penetration mode, the change in hardness with temperature is determined.

4.2.1 Expansion Mode

T_g of a polymer is usually determined by monitoring the volumetric or cubic expansion of a test specimen as a function of increasing temperature. Alternatively, T_g may be determined by following the linear or one-dimensional expansion of a test specimen with increasing temperature. For polymers, the method employing volumetric expansion is usually more sensitive. This is not generally the case, however, when the test specimen is a fiber-reinforced composite laminate wherein the thermal expansion is due wholly to the resin matrix and occurs mainly by expansion in the directions normal to the axes of the fibers. In the case of angle-ply laminates, thermal expansion occurs principally in the direction normal to the plane of the plies. The linear expansion technique was therefore used in the current tests.

To use this technique, a flat sample approximately 6.4 mm (0.25-in.) square is placed in the sample holder such that the plies lie in a horizontal direction. A probe with a flat end 2.5 mm (0.100-in.) in diameter rests on the sample. A one gram weight is placed on the probe to ensure contact with the sample. The probe is connected to a LVDT which senses displacement. During a run, displacement data are plotted on the ordinate and temperature on the abscissa; temperature is programmed at a preselected linear rate. If the Y-axis is calibrated (e.g., by using a block of pure aluminum), then the slope is the product of the coefficient of thermal expansion and the initial

thickness of the sample. For determination of T_g, however, it is not necessary that the displacement scale be calibrated.

The coefficient of thermal expansion (slope of the displacement-temperature curve) of a polymer is lowest for the glassy state. As the temperature is raised, the coefficient increases when the polymer passes from the glassy to the rubbery or elastomeric state. The transition from the glassy coefficient to the elastomeric value defines T_g. In practice, a number of small changes in the coefficient may be observed before and after the major change at T_g. These are called secondary transitions which can be associated with changes in the freedom of vibration in the polymer molecule.[a]

4.2.2 Penetration Mode

The experimental setup used in the penetration mode is the same as that used in the linear expansion mode, except that the sample end of the probe is a hemisphere, 2.5 mm (0.100-in.) diameter. A maximum weight of 100 grams may be placed on this probe.

The sample temperature is programmed at a preselected linear rate. The sample softens as it passes from the glassy to the rubbery state. This softening is recorded as a rather sharp displacement of the penetration probe and the mean temperature of the transition is taken as T_g. This displacement is opposite in direction to that measured in the expansion mode.

The penetration displacement observed with a fiber reinforced polymer is usually not as sharply defined as that seen with the neat polymer. In fact, significant penetration rarely is observed with an angle-ply laminate; under these conditions, the penetration probe may function as an expansion probe. At very high instrument sensitivity, slight penetration may be observed prior to expansion as the probe pierces the resin-rich surface layer of the laminate.

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[a] The transitions referred to here (including the glass transition) always occur over a temperature range. The reported values of the corresponding transition temperatures typically depend to a considerable extent on the experimental conditions of measurement and on how the data are interpreted.

4.2.3 T_g Tests Results

T_g determinations by expansion, and by penetration, after a moisture gain of 0.99 weight percent in a representative test specimen, are illustrated in Figure 48 and 49, respectively. The T_g from linear expansion measurements, conventionally taken at the second change in slope, yields a T_g value of 117°C (246°F) although the transition actually begins at about 67°C (154°F). In Figure 49, no penetration is discernible. Expansion was observed, however, giving a T_g of 124°C (257°F).

All additional T_g determinations for both T300/5208 and AS/3501-5A were made by linear expansion measurements. These results are presented in Figures 50 through 52.

4.3 Determination of Moisture Distribution

Moisture picked up from the environment, or during conditioning treatments at high humidity, resides initially close to the surfaces of the laminates, and diffuses to the core slowly. Drying operations remove moisture first from the surface layers. At temperatures which appear not to affect epoxy polymer (i.e., less than 100°C (212°F)) and for thicknesses of interest, diffusion processes are so slow that a reasonably uniform moisture distribution through the thickness is generally unlikely. The analytical prediction of moisture distribution may be made when saturation content and diffusivity are known, but the fact that initial moisture content and initial distribution are in general, unknown makes analytical prediction subject to error.

An experimental technique developed at Lockheed [9] was used to determine the moisture distribution for the laminates subjected to various environmental conditions in this program. At least three replicate specimens for each laminate type were used to obtain the required data. These were prepared in convenient size, such as 13 x 25 mm (0.5 x 1.0 in.). Care was taken to maintain undamaged surfaces and regular, smooth edges. Specimen weights and dimensions were determined. The specimens were then split into slabs of about 0.25 mm (0.01 in.) thick, preferably between plies to obtain reasonably parallel surfaces. This operation was accomplished with a standard laboratory microtome. The slabs were immediately weighed, then placed in a drying environment

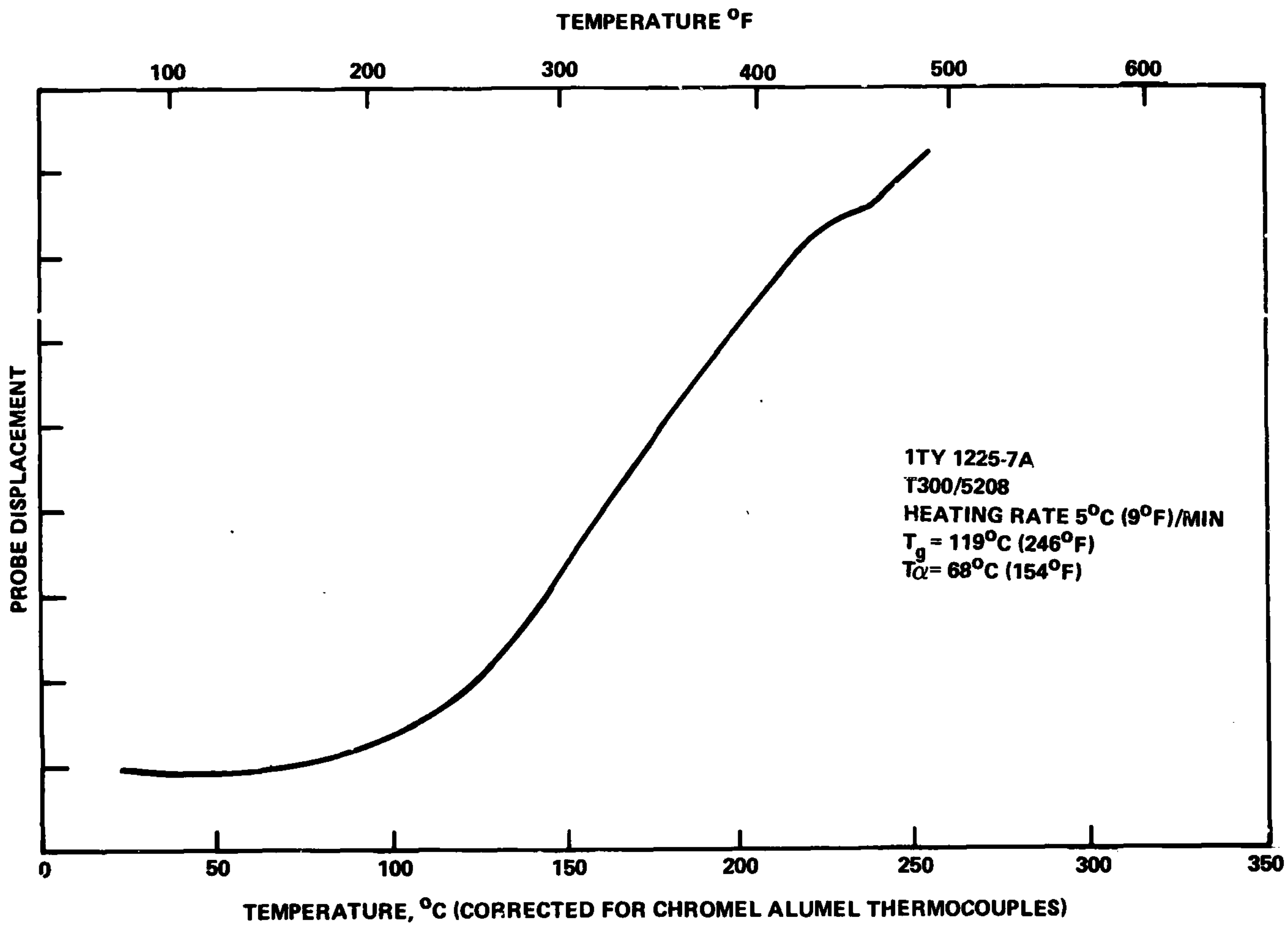


Figure 48. - T_g determination by linear expansion for specimen conditioned by water immersion at 93° C (200°F) to weight gain of .99% - T300/5208.

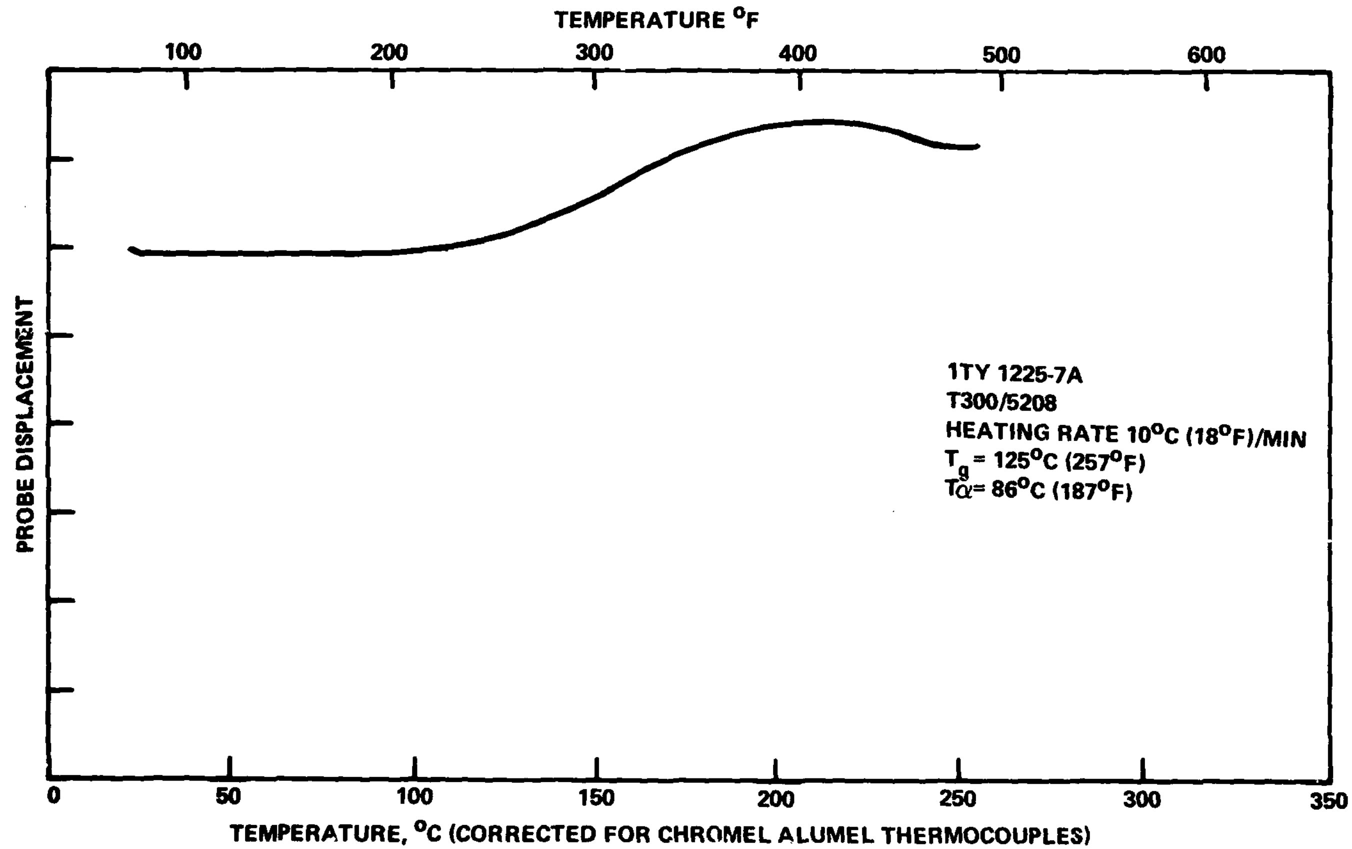


Figure 49. - T_g determination by penetration for specimen conditioned by water immersion at 93°C (200°F) to weight gain of .99% - T300/5208.

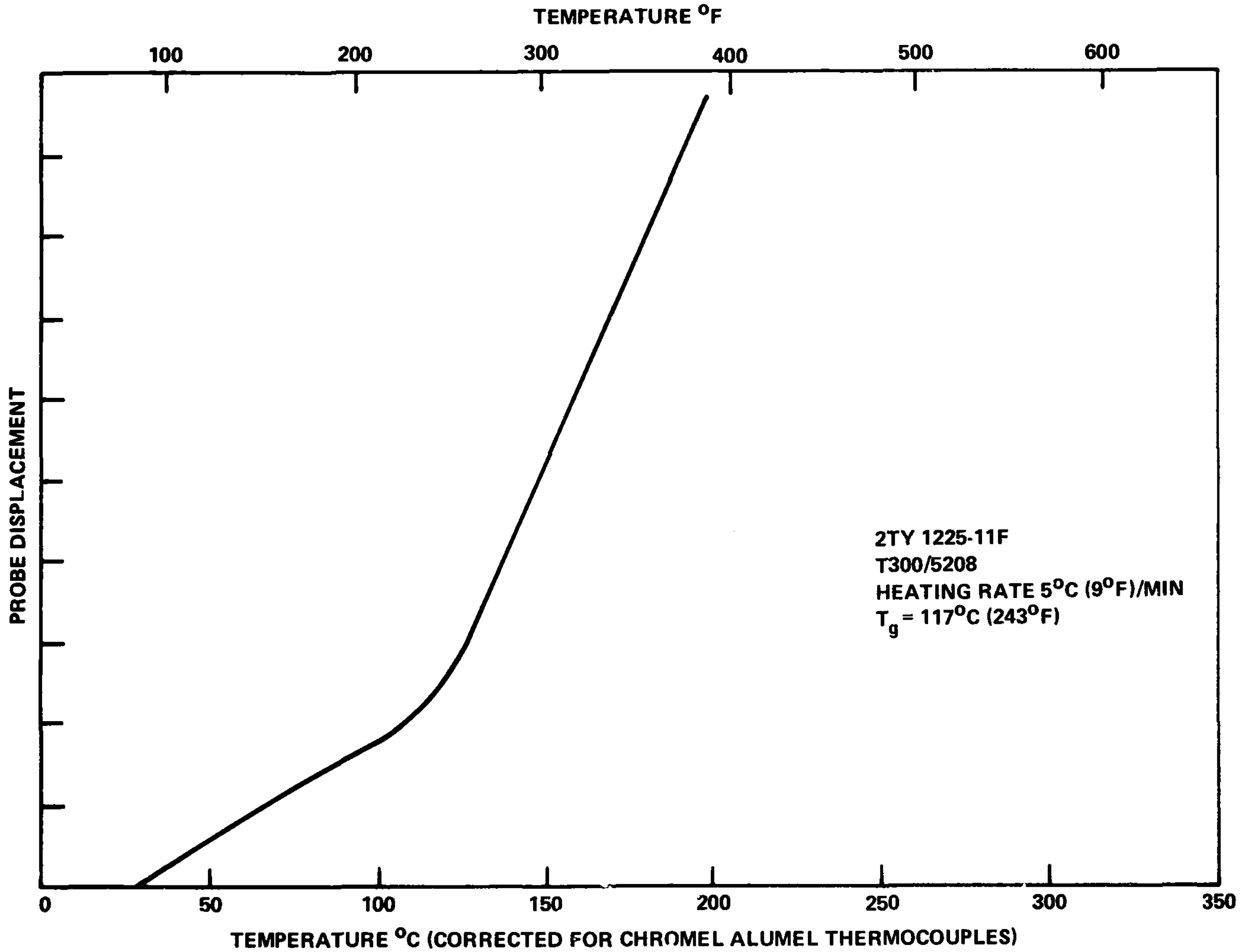


Figure 50. - T_g determination by linear expansion for specimen conditioned at 82°C (180°F) to weight gain of 1% - T300/5208 batch TY.

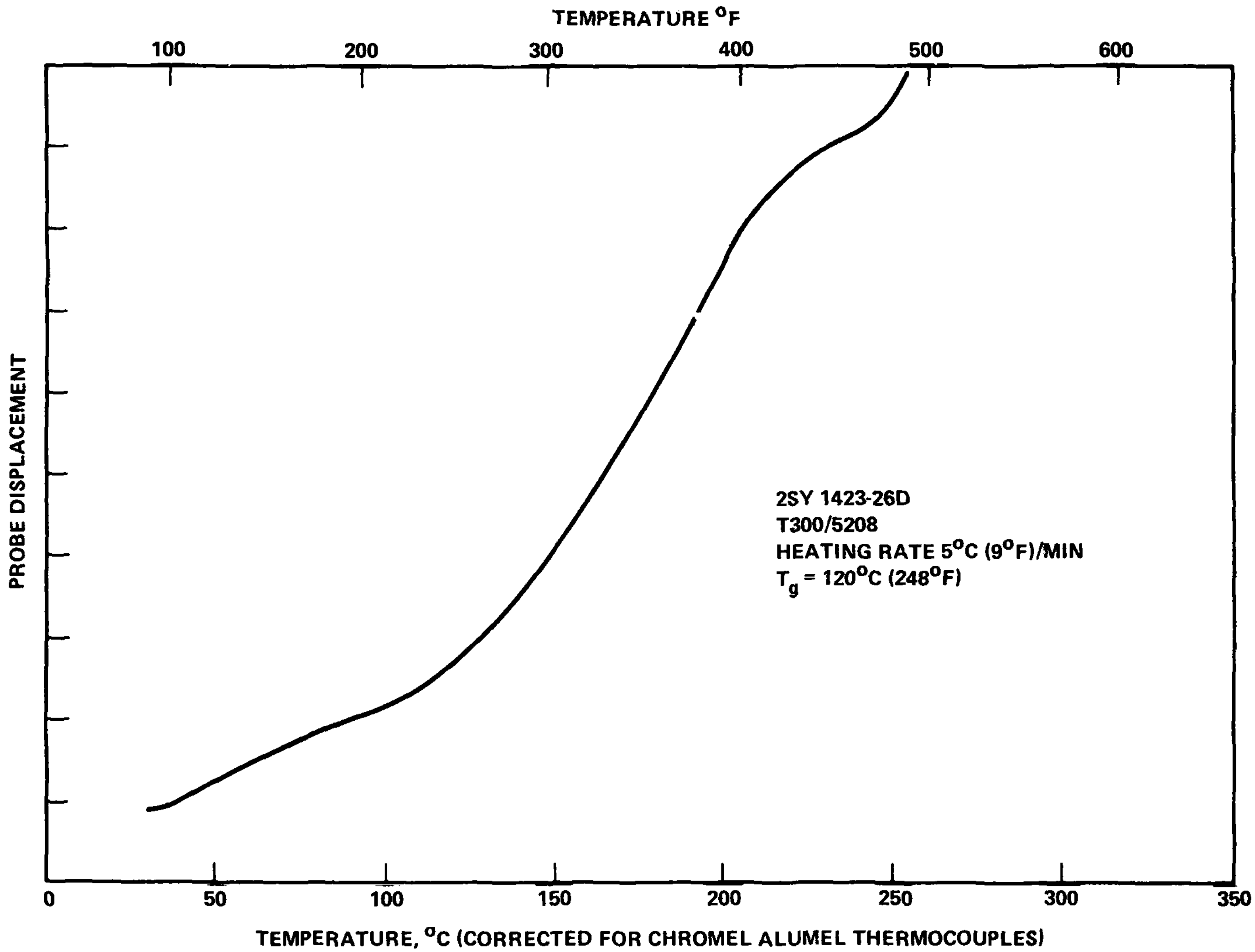


Figure 51. - T_g determination by linear expansion for specimen conditioned at 82°C (180°F) to weight gain of 1% - T300/5208 batch SY.

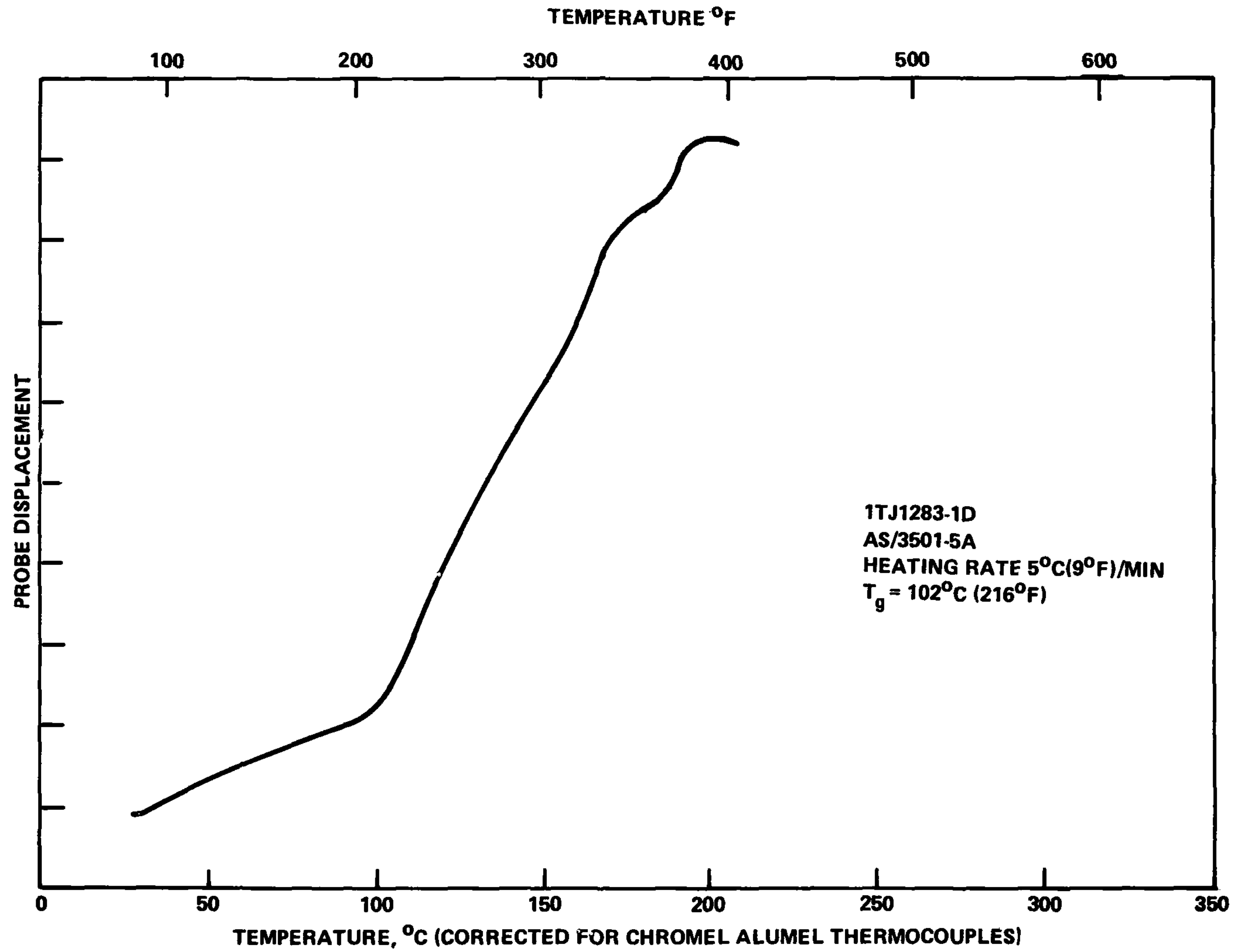


Figure 52. - T_g determination by linear expansion for specimen conditioned at 82°C (180°F) to weight gain of 1% - AS/3501-5A.

at 93°C (200°F) in vacuo over "Drierite", and the weight loss monitored until the original moisture content of each slab was determined.

Original weight and dimensional data provided a basis for determining average slab thickness. The weight loss for each slab was treated as an average value and plotted against median location. A plot through the test points provides an empirical moisture distrubution curve. For both materials, the distribution curve so obtained consistently shows about 0.1 weight percent of moisture less than that which the specimen actually picked up, as measured by weight, gain before and after the exposure. The difference, identified as "bound water", is attributed to chemical combination.

The effects of two uniform moisture distributions (low and high) and two non-uniform moisture distributions on compression strength were evaluated in this program. Baseline tests were conducted on specimens having nearly uniform moisture content of either 0.3 percent or 0.9 percent by weight. The 0.3 percent moisture content was obtained after simple storage under laboratory environment. A typical moisture distribution for specimens conditioned in this manner for 14 days is given in Figure 53. There was little additional change with 90 days in this environment.

The 0.9 percent uniform moisture level was obtained by conditioning under an environment of 82°C (180°F) and 90% RH for 90 days. Representative moisture distributions obtained after this controlled exposure are shown in Figures 54 and 55. A nearly uniform distribution was achieved after 12 weeks of conditioning.

This same technique was used to determine whether excessive moisture loss was incurred during testing. Samples were taken from test specimens immediately upon termination of the test. Testing time ranged from fifteen minutes for a single column length to a maximum of 40 minutes where one specimen was tested at two column lengths. This total elapsed time includes time necessary for fixture changes. The moisture distribution shown in Figure 56 was obtained after a test duration of approximately 30 minutes at 135°C (275°F) and is representative of the worst case. Moisture loss can be seen to be confined to surface plies. Moisture loss obtained from weight loss measurements on coupons placed in this test chamber along with the test specimens ranged from 0.25% - 0.38% and averaged 0.31%.

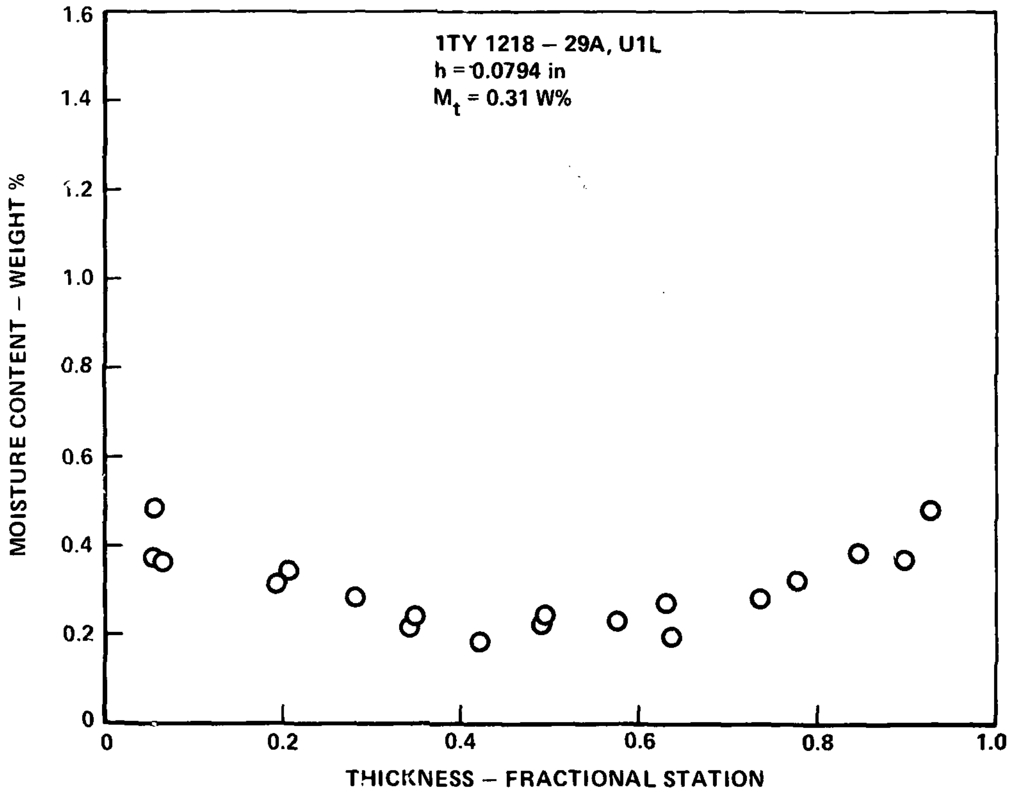


Figure 53. - Moisture distribution for T300/5208 specimen 1TY1218-29A (U1L) after 14 days at 40% RH and 22°C (72°F).

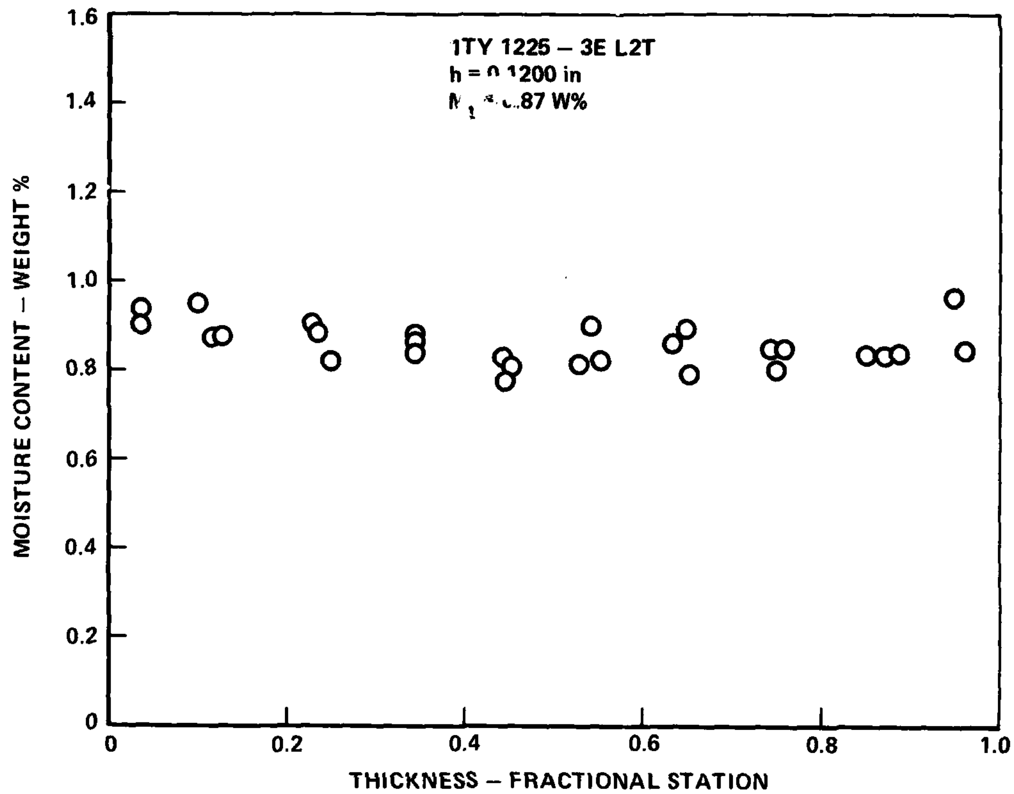


Figure 54. - Moisture distribution for T300/5208 specimen 1TY1225-3E (L2T) after 90 days at 90% RH and 82°C (180°).

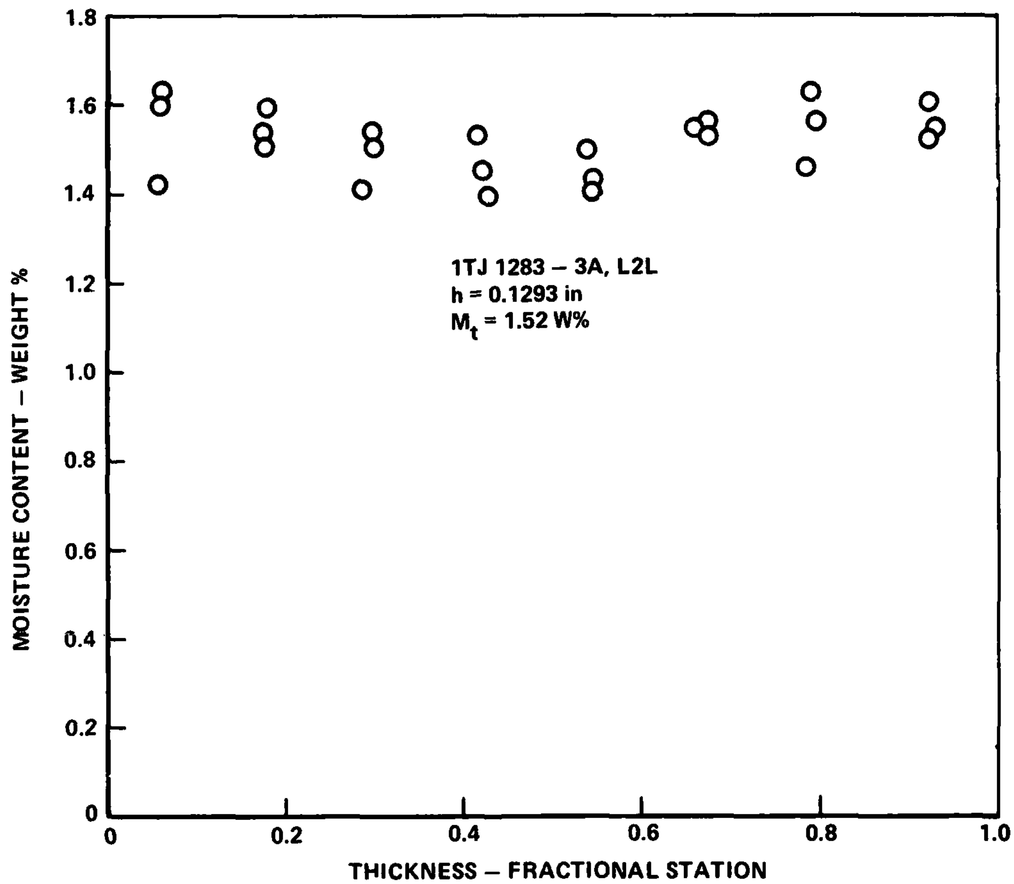


Figure 55. - Moisture distribution for AS/3501-5A specimen 1TJ1283-3A after 90 days at 90% RH and 82°C (180°F).

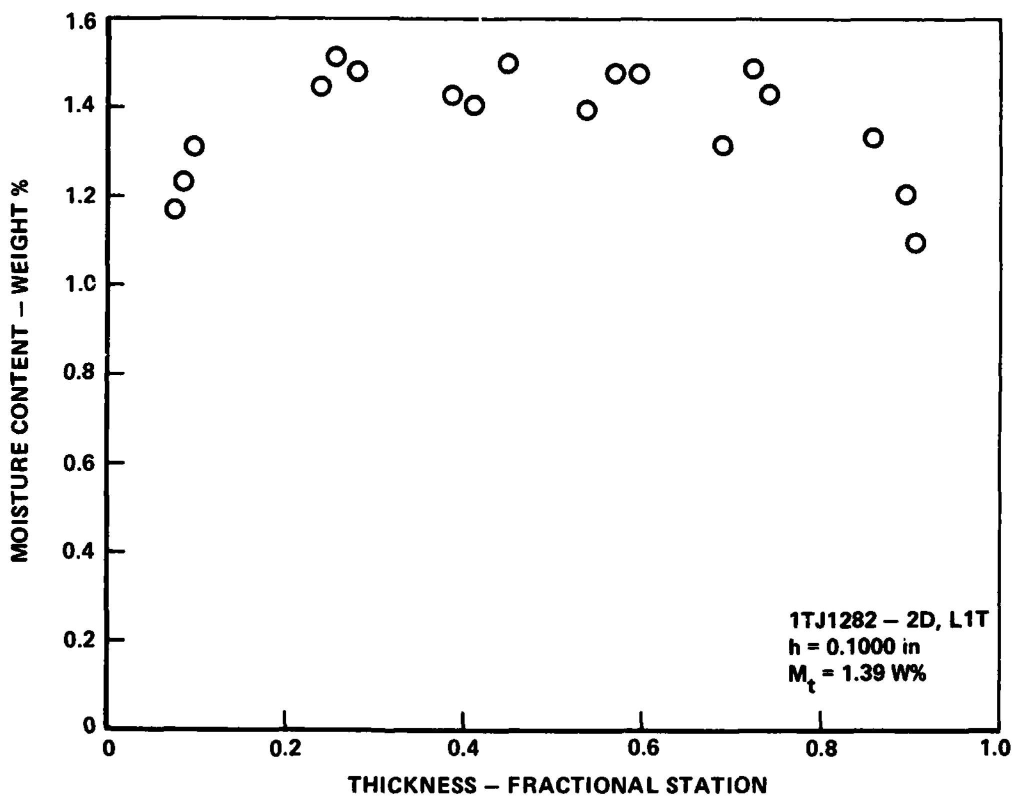


Figure 56. - Moisture distribution for AS/3501-5A specimen 1TJ1282-2D after testing at two column lengths at 135°C (275°F).

A number of tests in Phase III of the program were directed towards determining the effect of non-uniform moisture distribution on column compression. The condition in which the surface plies were highly saturated, while the central plies were still quite dry, was obtained by exposing previously dried specimens to 90% RH at 82°C (180°F) for one week, then testing immediately. The moisture distributions found in such specimens, designated Non-Uniform Moisture 1 (NUM1), are typified by the case shown in Figure 57.

A second non-uniform moisture distribution of interest is that in which one side is saturated and the other side is dry. This condition, designated Non-Uniform Moisture 2 (NUM2), was obtained by sealing one side of the specimen with adhesive-backed lead foil, placing in a 90% RH environment at 82°C (180°F) for one week, then testing immediately. A representative moisture distribution for specimens prepared in this manner is shown in Figure 58.

In monitoring the effects of environmental exposure some 30 analyses similar to Figures 52 to 58 were conducted, the results of which are included in Appendix C.

4.4 Static Tension Tests

Static tension tests were conducted in a 0.53 MN (120 kip) Baldwin Universal test machine following procedures similar to ANSI/ASTM D3039-76. A set of MTS hydraulic self-aligning grips was used. Specimens were positioned by placing the coupon edge against a specially constructed alignment fixture. This assured good end-to-end alignment since specimen width did not vary more than 0.05 mm (0.002 in.). Specimen dimensions are given in Section 1.3.1. The deflection was measured using a 50.8 mm (2.0 in.) extensometer. A transverse extensometer was also used for the room temperature tests in an attempt to obtain data on Poisson's ratio. Load-deflection curves were continuously read out on an x-y recorder. Tests were conducted at a cross head speed of 1.3 mm/min (0.05 in./min.). For the 135°C (275°F), 93°C (200°F), and -54°C (-65°F) tests the coupon was surrounded by a chamber which was supplied with either hot air or liquid nitrogen, as required.

Three coupons of each of the six laminate types (L1, longitudinal; L1, transverse; L2, longitudinal; L2, transverse; U1, longitudinal; U1, transverse)

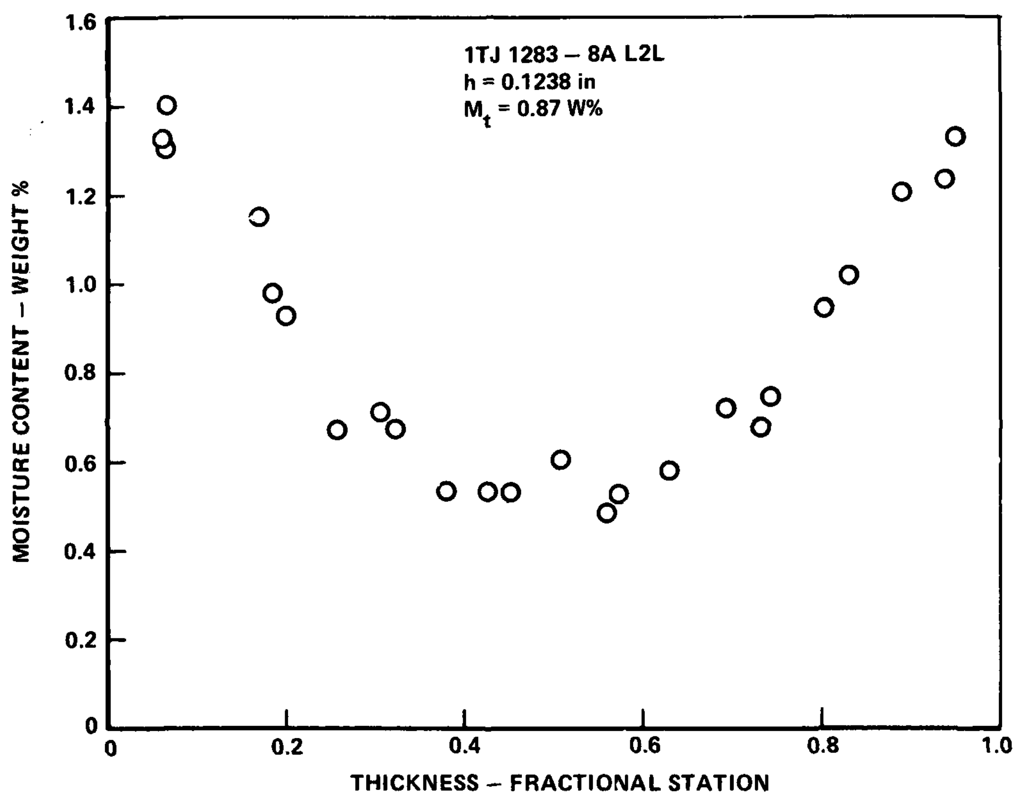


Figure 57. - Moisture distribution for AS/3501-5A specimen 1TJ1283-8A (L2L) after special conditioning to obtain non-uniform symmetrical distribution (NUM1).

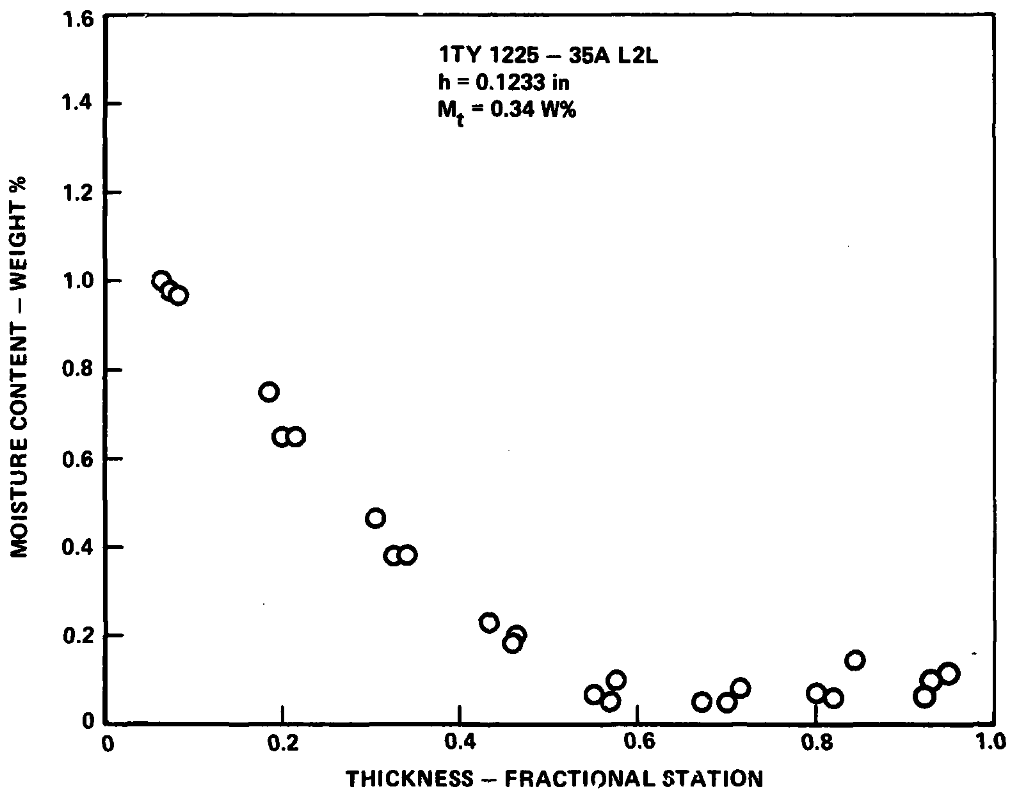


Figure 58. - Moisture distribution for T300/5208 specimen 1TJ1282-5C (L2L) after special conditioning to obtain non-uniform unsymmetrical distribution (NUM2).

of T300/5208 were tested at each of four temperatures: -54, 22, 93 and 135°C (-65, 72, 200 and 275°F), for both "dry" and "wet" conditions, as described in Section 4.3. Three replicates of each of these six laminates of AS/3501-5A were tested at two conditions: 22°C (72°F), dry and 135°C (275°F), wet. "Dry" specimens were conditioned a minimum of two weeks at 22°C (72°F) and 40% R.H. Wet specimens were conditioned a minimum of 10 weeks at 82°C (180°F) and 90% R.H. Test results are presented in Tables 12 through 20, and averaged data are summarized in Tables 21 through 23.

Since only three specimens were tested per a condition, data dispersion cannot be determined and interpretation is difficult. In general, however, the following observations can be made:

- For T300/5208 material all of the laminates show very little change due to moisture or temperature with the exception of the 90°-unidirectional laminate U1T which exhibits a strength decrease due to moisture in the range of 30 to 60%. The modulus of this laminate appears to decrease with increase in temperature and is further affected by the moisture/temperature combination at 135°C (275°F).

- Shape of the stress-strain curve of the 0°-unidirectional laminate seems to be affected by moisture. The stress-strain curve which for the dry condition is non-linear with steadily increasing modulus becomes very linear to failure after moisture conditioning at all four temperatures.

- In AS/3501-5A material the combination of moisture and elevated temperature appears to affect only the failure strain in the fiber dominated laminates L2L and U1L resulting in an apparent increase.

- Matrix dominated laminates L1L, L1T, L2T and U1T of AS/3501-5A all exhibit a decreased strength and modulus with little change in failure strain at the wet 135°C (275°F) condition.

- The AS/3501-5A U1T laminate appears to be more severely affected by the wet 135°C (275°F) condition than the same laminate of T300/5208.

- For most of the laminates and test conditions, the stress-strain curves could be characterized as bilinear, having an initial straight line portion (E_{ai}) followed by a smooth transition to another straight line (E_{af}) which continues to failure. Exceptions to this type of response are noted for L1T at -54°C (-65°F) and at 93°C (200°F); these curves were linear to failure.

- The nature of the failure at room temperature varied considerably with the layup. Failures in laminate L1L involved considerable delamination and splitting, with the outer plies failing at a 45° angle on one

TABLE 12a

TENSION TEST RESULTS FOR DRY LAMINATE L1 - T300/5208

	Specimen ID	Test Temp °F	Avg. Area in.^{2}	Ult. Load $P_{ult.}$, lbs	Ult. Stress $\sigma_{ult.}$, ksi	Ult. Strain $\epsilon_{ult.}$, in/in.	Slope Deviation Load P_y, lbs.	Slope Deviation Stress σ_y, ksi	Slope Deviation Strain ϵ_y, in/in in 2 in.	Initial Apparent Modulus of Elasticity E_{ai}, psi x 10^6	Final Apparent Modulus of Elasticity E_{af}, psi x 10^6	Poisson's Ratio ν	Failure[a] Location
	2TY 1218-3A	-65	0.0806	5440	67.5	0.0090	3600	44.7	0.0057	7.56	6.90	-	W
	1TY 1224-4B	-65	0.0833	5980	71.8	0.0090	3280	39.4	0.0042	7.68	6.68	-	G
	1TY 1226-4A	-65	0.0806	5180	64.2	0.0088	3300	40.9	0.0053	7.82	6.64	-	G
Quasi-Isotropic Laminate L1 - Longitudinal $(0/45/90/-45_2/90/45/0)_s$ W.R.T. Load	2TY 1218-23B	72	0.0821	5710	69.6	0.0094	4300	52.4	0.0068	7.68	6.40	0.283	G
	1TY 1224-23A	72	0.0827	6430	78.4	0.0110	4300	52.0	0.0070	7.42	6.46	0.280	G
	1TY 1226-5B	72	0.0815	6620	81.2	0.0112	4530	55.5	0.0073	7.66	6.56	0.256	G
	2TY 1218-12A	200	0.0801	6008	75.0	0.0107	-	-	-	7.46	-	-	W
	2TY 1218-12B	200	0.0810	5880	72.6	0.0099	-	-	-	7.50	-	-	G
	1TY 1226-38A	200	0.0814	5680	69.8	0.0092	-	-	-	7.58	-	-	G
	2TY 1218-16B	275	0.0816	6530	80.1	0.0105	-	-	-	7.48	-	-	G
	2TY 1218-9A	275	0.0804	6020	74.8	0.0101	-	-	-	7.51	-	-	G
	2TY 1218-21B	275	0.0822	6080	74.0	0.0100	-	-	-	7.46	-	-	G
	2TY 1218-11E	-65	0.0821	5800	70.6	0.0086	-	-	-	8.13	-	-	G
	2TY 1218-18E	-65	0.0819	5560	67.8	0.0083	-	-	-	8.14	-	-	1/2 W
	1TY 1226-11E	-65	0.0822	5560	67.6	0.0092	-	-	-	7.26	-	-	G
Quasi-Isotropic Laminate L1 - Transverse $(90/45/0/-45_2/0/45/90)_s$ W.R.T. Load	2TY 1218-8D	72	0.0817	6240	76.4	0.0104	3920	48.0	0.0064	7.52	7.08	0.282	G
	2TY 1218-16F	72	0.0810	6720	83.0	0.0111	3990	49.3	0.0064	7.72	7.14	0.262	G
	1TY 1226-11D	72	0.0817	6040	73.9	0.0104	3870	47.4	0.0064	7.38	6.96	0.276	G
	2TY 1218-17E	200	0.0818	6040	73.8	0.0112	-	-	-	7.44	-	-	W
	1TY 1226-7F	200	0.0813	5840	71.8	0.0099	-	-	-	7.20	-	-	1/2 W
	1TY 1226-16F	200	0.0806	6140	76.2	0.0112	-	-	-	7.14	-	-	G
	1TY 1226-1D	275	0.0812	5350	65.9	-	-	-	-	7.29	-	-	G
	1TY 1226-17F	275	0.0810	5800	71.6	0.0115	-	-	-	7.59	-	-	W
	1TY 1226-3E	275	0.0816	5700	69.8	0.0102	-	-	-	7.54	-	-	G

a - G - gage section one inch from tabs. W - between 1/2 and 1 specimen width (1-inch) away from tab. 1/2 W - between tab end and 1/2 width from tab end.

TABLE 12b

TENSION TEST RESULTS FOR DRY LAMINATE L1- T300/5208

	Specimen ID	Test Temp. °C	Average Area mm^2	Ultimate Load P_{ult}, KN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm	Slope Deviation Load P_y, KN	Slope Deviation Stress σ_y, MPa	Slope Deviation Strain ϵ_y, mm/mm in 51 mm	Initial Apparent Modulus of Elasticity E_{ai}, GPa	Final Apparent Modulus of Elasticity E_{af}, GPa	Poisson's Ratio ν	Failure Location [a]
Quasi-Isotropic Laminate L1 - Longitudinal $(0/45/90/-45_2/90/45/0)_s$ W.R.T. Load	2TY-1218-3A	-54	52.0	24.2	465	0.0090	16.0	308	0.0057	52	47	-	W
	1TY-1224-4B	-54	53.7	26.6	495	0.0090	14.6	272	0.0042	53	46	-	G
	1TY-1226-4A	-54	52.0	23.0	443	0.0088	14.7	282	0.0053	54	46	-	G
	2TY-1218-23B	22	53.0	25.4	480	0.0094	19.1	361	0.0068	53	44	0.283	G
	1TY-1224-23A	22	53.4	28.8	541	0.0110	19.1	358	0.0070	51	44	0.280	G
	1TY-1226-5B	22	52.6	29.4	560	0.0112	20.2	383	0.0073	53	45	0.256	G
	2TY-1218-12A	93	51.7	26.7	517	0.0107	-	-	-	51	-	-	W
	2TY-1218-12B	93	52.3	26.2	501	0.0099	-	-	-	52	-	-	G
	1TY-1226-38A	93	52.5	25.3	481	0.0092	-	-	-	52	-	-	G
	2TY-1218-16B	135	52.6	29.0	552	0.0105	-	-	-	52	-	-	G
	2TY-1218-9A	135	51.9	26.8	516	0.0101	-	-	-	52	-	-	G
	2TY-1218-21B	135	53.0	27.0	510	0.0100	-	-	-	51	-	-	G
Quasi-Isotropic Laminate L1 - Transverse $(90/45/0/-45_2/0/45/90)_s$ W.R.T. Load	2TY-1218-11E	-54	53.0	25.8	487	0.0086	-	-	-	56	-	-	G
	2TY-1218-18E	-54	52.8	24.7	467	0.0083	-	-	-	56	-	-	1/2 W
	1TY-1226-11E	-54	53.0	24.7	466	0.0092	-	-	-	59	-	-	G
	2TY-1218-8D	22	52.7	27.8	527	0.0104	17.4	331	0.0064	52	48	0.282	G
	2TY-1218-16F	22	52.3	29.9	572	0.0111	17.7	340	0.0064	53	49	0.262	G
	1TY-1226-11D	22	52.7	26.9	510	0.0104	17.2	327	0.0064	51	48	0.276	G
	2TY-1218-17E	93	52.8	26.9	509	0.0112	-	-	-	51	-	-	W
	1TY-1226-7F	93	52.5	26.0	495	0.0099	-	-	-	50	-	-	1/2 W
	1TY-1226-16F	93	52.0	27.3	525	0.0112	-	-	-	49	-	-	G
	1TY-1226-1D	135	52.4	23.8	454	-	-	-	-	50	-	-	G
	1TY-1226-17F	135	52.3	25.8	494	0.0115	-	-	-	52	-	-	W
	1TY-1226-3E	135	52.6	25.4	481	0.0102	-	-	-	52	-	-	G

a - G = gage section one inch from tabs. W = between 1/2 and 1 specimen width (1-inch) away from tab.
1/2 W = between tab end and 1/2 width from tab end.

TABLE 13a

TENSION TEST RESULTS FOR WET LAMINATE L1 - T300/5208

	Specimen ID	Test Temp. °F	Average Area in.^{2}	Ultimate Load P_{ult}, lbs	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in.	Slope Deviation Load P_y, lbs	Slope Deviation Stress σ_y, ksi	Slope Deviation Strain, ϵ_y, in./in. in 2 in.	Initial Apparent Modulus of Elasticity E_{ai}, psi x 10^6	Final Apparent Modulus of Elasticity E_{af}, psi x 10^6	Poisson's Ratio ν	Failure[a] Location
Quasi-Isotropic Laminate L1 - Longitudinal $(0/45/90/-45_2/90/45/0)_S$ W.R.T. Load	2TY1218-17B	-65	0.0818	6620	80.9	0.0113	5124	62.6	0.0081	7.74	5.97	-	G
	2TY1218-6G	-65	0.0811	5200	64.1	0.0085	-	-	-	7.87	-	-	G
	1TY1224-3B	-65	0.0830	6500	78.3	0.0101	-	-	-	7.74	-	-	W
	1TY1218-20B	72	0.0815	6560	80.5	0.0101	-	-	-	7.97	-	.150	G
	1TY1224-38A	72	0.0817	6800	83.2	0.0099	-	-	-	8.10	-	.310	G
	1TY1224-10B	72	0.0829	6260	75.5	0.0101	-	-	-	7.62	-	.200	1/2 W
	2TY1218-14A	200	0.0804	6400	79.6	0.0104	-	-	-	7.74	-	-	W
	2TY1218-7B	200	0.0809	6220	76.9	0.0096	-	-	-	8.12	-	-	G
	1TY1226-9A	200	0.0814	6380	78.4	0.0105	-	-	-	7.70	-	-	G
	2TY1218-33B	275	0.0814	6000	73.4	0.0107	6000	73.7	0.0094	6.87	5.73	-	G
	1TY1224-32B	275	0.0837	6300	75.3	0.0120	5424	64.8	0.0097	6.34	4.58	-	G
	1TY1226-4B	275	0.0819	6080	74.3	0.0116	5100	62.3	0.0084	7.29	5.19	-	G
Quasi-Isotropic Laminate L1 - Transverse $(90/45/0/-45_2/0/45/90)_S$ W.R.T. Load	2TY1218-7E	-65	0.0813	5980	73.6	0.0099	-	-	-	7.61	-	-	1/2 W
	2TY1218-12F	-65	0.0818	5900	72.1	0.0100	-	-	-	7.17	-	-	1/2 W
	2TY1218-19F	-65	0.0816	6380	78.2	0.0104	-	-	-	7.55	-	-	G
	1TY1224-1C	72	0.0813	6440	79.2	b	b	b	b	7.54	b	.296	G
	1TY1224-7C	72	0.0824	6620	79.9	0.0107	-	-	-	7.59	-	.360	G
	1TY1224-7F	72	0.0836	6700	80.1	0.0104	-	-	-	7.74	-	.245	W
	2TY1218-19C	200	0.0808	6040	74.8	0.0107	-	-	-	7.61	-	-	G
	1TY1226-18C	200	0.0807	5620	69.6	0.0094	-	-	-	7.52	-	-	G
	1TY1226-12F	200	0.0824	6400	78.4	0.0106	-	-	-	7.58	-	-	G
	2TY1218-13E	275	0.0828	5880	71.5	0.0099	-	-	-	7.24	-	-	G
	2TY1218-8F	275	0.0818	5620	68.7	0.0101	-	-	-	7.22	-	-	G
	1TY1224-11E	275	0.0830	6260	75.4	0.0106	-	-	-	7.23	-	-	G

a - G - gage section one inch from tabs. W - between 1/2 and 1 specimen width (1-inch) away from tab. 1/2 W - between tab end and 1/2 width from tab end.

b - *Extensometer slipped - inaccurate reading.*

TABLE 13 b

TENSION TEST RESULTS FOR WET LAMINATE L1 - T300/5208

	Specimen ID	Test Temp. °C	Average Area mm^2	Ultimate Load P_{ult}, KN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm	Slope Deviation Load P_y, KN	Slope Deviation Stress σ_y, MPa	Slope Deviation Strain ϵ_y, mm/mm In 51 mm	Initial Apparent Modulus of Elasticity E_{ai}, GPa	Final Apparent Modulus of Elasticity E_{af}, GPa	Poisson's Ratio ν	Failure Location [a]
Quasi-Isotropic Laminate L1 - Longitudinal $(0/45/90/-45_2/90/45/0)_s$ W.R.T. Load	2TY-1218-17B	-54	52.7	29.4	558	0.0113	22.8	431	0.0081	53	41	-	G
	2TY-1218-6G	-54	52.3	23.1	442	0.0085	-	-	-	54	-	-	G
	1TY-1224-3B	-54	53.5	28.9	540	0.0101	-	-	-	53	-	-	W
	1TY-1218-20B	22	52.6	29.2	555	0.0101	-	-	-	55	-	0.150	G
	1TY-1224-38A	22	52.7	30.2	574	0.0099	-	-	-	56	-	0.310	G
	1TY-1224-10B	22	53.5	27.8	520	0.0101	-	-	-	52	-	0.200	1/2 W
	2TY-1218-14A	93	51.9	28.5	549	0.0104	-	-	-	53	-	-	W
	2TY-1218-7B	93	52.2	27.7	530	0.0096	-	-	-	56	-	-	G
	1TY-1226-9A	93	52.5	28.4	540	0.0106	-	-	-	53	-	-	G
	2TY-1218-33B	135	52.5	26.[illegible]	506	0.0107	26.7	508	0.0094	47	39	-	G
	1TY-1224-32B	135	53.3	28.0	519	0.0120	24.1	447	0.0097	44	31	-	G
	1TY-1226-4B	135	52.8	27.0	512	0.0116	22.7	429	0.0084	50	35	-	G
Quasi-Isotropic Laminate L1-Tranverse $(90/45/0/-45_2/0/45/90)_s$ W.R.T. Load	2TY-1218-7E	-54	52.4	26.2	507	0.0099	-	-	-	52	-	-	1/2 W
	2TY-1218-12F	-54	52.7	26.2	497	0.0100	-	-	-	49	-	-	1/2 W
	2TY-1218-19F	-54	52.6	28.4	539	0.0104	-	-	-	52	-	-	G
	1TY-1224-1C	22	52.4	28.6	546	b	b	b	b	52	b	.296	G
	1TY-1224-7C	22	53.1	29.4	551	0.0107	b	b	b	52	-	.360	G
	1TY-1224-7F	22	53.9	29.8	552	0.0104	-	-	-	53	-	.245	W
	2TY-1218-19C	93	52.1	26.9	516	0.0107	-	-	-	52	-	-	G
	1TY-1226-18C	93	52.1	25.0	480	0.0094	-	-	-	52	-	-	G
	1TY-1226-12F	93	53.2	28.5	540	0.0106	-	-	-	52	-	-	G
	2TY-1218-13E	135	53.4	26.1	493	0.0099	-	-	-	50	-	-	G
	2TY-1218-8F	135	52.7	25.0	474	0.0101	-	-	-	50	-	-	G
	1TY-1224-11E	135	53.5	27.8	520	0.0106	-	-	-	50	-	-	G

a - G = gage section one inch from tabs. W = between 1/2 and 1 specimen width (1-inch) away from tab. 1/2 W - between tab end and 1/2 width from tab end.

b - Extensometer slipped - inaccurate reading.

TABLE 14a

TENSION TEST RESULTS FOR DRY LAMINATE L2 - T300/5208

	Specimen ID	Test Temp °F	Average Area in.²	Ultimate Load $P_{ult.}$, lbs	Ultimate Stress $\sigma_{ult.}$, ksi	Ultimate Strain $\epsilon_{ult.}$, in/in	Slope Deviation Load P_y, lbs.	Slope Deviation Stress σ_y, ksi	Slope Deviation Strain ϵ_y, in/in in 2 in.	Initial Modulus of Elasticity E_{ei}, psi x 10^6	Final Apparent Modulus of Elasticity E_{af}, psi x 10^6	Poisson's Ratio ν	Failure Location[a]
67% - 0° Laminate L2 - Longitudinal (0/45/0_2/-45/0_2/45/0_2/-45/0)s W.R.T. Load	2TY 1225-38B	-65	0.1204	18,620	154.7	0.0094	-	-	-	15.84	-	-	1/2 W
	2TY 1226-35B	-65	0.1205	18,240	151.3	- b	-	-	-	14.32	-	-	G
	2TY 1226-40B	-65	0.1216	18,540	152.4	0.0100	-	-	-	15.15	-	-	W
	1TY 1225-22A	72	0.1213	18,500	152.5	0.0101	-	-	-	14.68	-	0.522	G
	1TY 1225-34A	72	0.1201	18,920	157.6	0.0105	-	-	-	14.82	-	0.594	1/2 W
	2TY 1226-26A	72	0.1217	16,820	138.2	0.0094	-	-	-	14.76	-	0.592	1/2 W
	1TY 1225-6A	200	0.1211	20,200	166.8	0.0115	-	-	-	14.74	-	-	1/2 W
	1TY 1225-12A	200	0.1222	18,260	149.4	0.0101	-	-	-	14.66	-	-	1/2 W
	2TY 1226-2B	200	0.1212	20,780	171.4	0.0115	-	-	-	14.66	-	-	W
	2TY 1225-3A	275	0.1220	19,360	158.7	0.0099	-	-	-	15.81	-	-	W
	1TY 1225-21A	275	0.1206	18,880	156.5	0.0110	-	-	-	14.83	-	-	W
	1TY 1225-37A	275	0.1205	19,160	159.0	0.0108	-	-	-	13.86	-	-	G
67% - 0° Laminate L2 - Transverse (90/45/90_2/-45/90_2/45/90_2/-45/90)s W.R.T. Load	2TY 1225-2D	-65	0.1217	2,585	21.2	0.0128	1865	15.3	0.0053	2.52	0.72	-	1/2 W
	2TY 1226-11C	-65	0.1208	2,485	21.2	0.0120	1525	12.6	0.0044	2.82	0.55	-	1/2 W
	2TY 1226-7E	-65	0.1221	2,510	20.6	0.0121	1595	13.1	0.0043	2.64	0.63	-	1/2 W
	1TY 1225-1D	72	0.1209	2,525	20.6	0.0111	1940	16.0	0.0061	2.62	0.70	0.033	G
	1TY 1225-3D	72	0.1217	2,305	18.9	0.0077	1950	16.0	0.0062	2.60	1.14	0.042	1/2 W
	2TY 1225-8D	72	0.1226	2,630	21.4	0.0118	2040	16.6	0.0077	2.19	0.88	0.029	G
	2TY 1225-15C	200	0.1218	2,575	21.1	0.0118	1865	15.3	0.0060	2.54	1.05	-	1/2 W
	2TY 1225-4D	200	0.1218	2,600	21.3	0.0116	1710	14.0	0.0055	2.52	0.74	-	G
	2TY 1225-14F	200	0.1215	2,520	20.7	0.0116	1670	13.7	0.0056	2.46	1.18	-	W
	1TY 1225-10D	275	0.1232	2,560	20.8	0.0098	1000	8.1	0.0031	2.62	c	-	G
	2TY 1225-17D	275	0.1209	2,635	21.8	0.0108	1450	12.0	0.0046	2.58	0.97	-	G
	2TY 1226-1E	275	0.1209	2,640	21.8	0.0105	1670	13.8	0.0054	2.55	1.49	-	-

a - G - gage section one inch from tabs. W - between 1/2 and 1 specimen width (1-inch) away from tab. 1/2 W - between tab end and 1/2 width from tab end.

b - Extensometer froze, inaccurate reading.

c - No final linear region.

TABLE 14b

TENSION TEST RESULTS FOR DRY LAMINATE L2 - T300/5208

	Specimen ID	Test Temp. °C	Average Area mm^2	Ultimate Load P_{ult}, KN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm	Slope Deviation Load P_y, KN	Slope Deviation Stress σ_y, MPa	Slope Deviation Strain ϵ_y, mm/mm in 51 mm	Initial Apparent Modulus of Elasticity E_{ai}, GPa	Final Apparent Modulus of Elasticity E_{af}, GPa	Poisson's Ratio ν	Failure Location [a]
67% - 0° Laminate L2 - Longitudinal $(0/45/0_2/-45/0_2/45/0_2/-45/0)_s$ W.R.T. Load	2TY-1225-38B	-54	77.7	82.8	1067	0.0094	-	-	-	109	-	-	1/2 W
	2TY-1226-35B	-54	77.7	81.1	1043	b	-	-	-	98	-	-	G
	2TY-1226-40B	-54	78.4	82.5	1051	0.0100	-	-	-	104	-	-	W
	1TY-1225-22A	22	78.2	82.3	1051	0.0101	-	-	-	101	-	0.522	G
	1TY-1225-34A	22	77.5	84.2	1087	0.0105	-	-	-	102	-	0.594	1/2 W
	2TY-1226-26A	22	78.5	74.8	953	0.0094	-	-	-	102	-	0.592	1/2 W
	1TY-1225-6A	93	78.1	90.0	1150	0.0115	-	-	-	102	-	-	1/2 W
	1TY-1225-12A	93	78.8	81.2	1030	0.0101	-	-	-	101	-	-	1/2 W
	2TY-1226-2B	93	78.2	92.4	1182	0.0115	-	-	-	101	-	-	W
	2TY-1225-3A	135	78.7	86.1	1094	0.0099	-	-	-	109	-	-	W
	1TY-1225-21A	135	77.8	84.0	1079	0.0110	-	-	-	102	-	-	W
	1TY-1225-37A	135	77.7	85.2	1096	0.0108	-	-	-	95	-	-	G
67% - 0° Laminate L2 - Transverse $(90/45/90/45/90_2/45/90_2/-45/90)_s$ W.R.T. Load	2TY-1225-2D	-54	78.5	11.5	146	0.0128	8.3	105	0.0056	17	5.0	-	1/2 W
	2TY-1226-11C	-54	77.9	11.0	146	0.0120	6.8	86	0.0044	19	3.8	-	1/2 W
	2TY-1226-7E	-54	78.8	11.2	142	0.0121	7.1	90	0.0043	18	4.3	-	1/2 W
	1TY-1225-1D	22	78.0	11.2	142	0.0111	8.6	110	0.0061	18	4.8	0.033	G
	1TY-1225-3D	22	78.5	10.2	130	0.0077	8.7	110	0.0062	18	7.8	0.042	1/2 W
	2TY-1225-6D	22	79.1	11.7	147	0.0118	9.1	114	0.0077	15	6.1	0.029	G
	2TY-1225-15C	93	78.6	11.4	145	0.0118	8.3	105	0.0060	17	7.2	-	1/2 W
	2TY-1225-4D	93	78.6	11.6	147	0.0116	7.6	96	0.0055	17	5.1	-	G
	2TY-1225-14F	93	78.4	11.2	143	0.0116	7.4	94	0.0056	17	8.1	-	W
	1TY-1225-10D	135	79.5	11.4	143	0.0098	4.4	56	0.0031	18	c	-	G
	2TY-1225-17D	135	78.0	11.7	150	0.0108	6.4	83	0.0046	18	6.7	-	G
	2TY-1225-1E	135	78.0	11.7	150	0.0105	7.4	95	0.0054	17	10.3	-	-

a - G = gage section one inch from tabs. W = between 1/2 and 1 specimen width (1-inch) away from tab. 1/2 W = between tab end and 1/2 width from tab end.

b - Extensometer froze, inaccurate reading.

c - No final linear region.

TABLE 15a

TENSION TEST RESULTS FOR WET LAMINATE L2 - T300/5208

	Specimen ID	Test Temp. °F	Average Area in.^{2}	Ultimate Load P_{ult}, lbs	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in.	Slope Deviation Load P_y, lbs	Slope Deviation Stress σ_y, ksi	Slope Deviation Strain, ϵ_y, in./in. in 2 in.	Initial Apparent Modulus of Elasticity E_{ai}, psi x 10^6	Final Apparent Modulus of Elasticity E_{af}, psi x 10^6	Poisson's Ratio ν	Failure[a] Location
67% - 0° Laminate L2 - Longitudinal $(0/45/0_2/-45/0_2/45/0_2/-45/0)_s$ W.R.T. Load	1TY1225-9A	-65	0.1211	18,920	156.2	0.0106	-	-	-	15.21	-	-	1/2 W
	1TY1225-20A	-65	0.1210	15,280	126.3	0.0089	-	-	-	14.64	-	-	1/2 W
	2TY1226-8B	-65	0.1211	19,980	164.9	0.0117	-	-	-	14.09	-	-	1/2 W
	2TY1225-14B	72	0.1222	20,080	164.3	0.0105	-	-	-	15.58	-	0.300	G
	2TY1225-1G	72	0.1208	20,860	172.7	b	-	-	-	15.76	-	0.200	W
	2TY1226-15B	72	0.1216	18,500	152.1	0.0096	-	-	-	15.91	-	0.175	1/2 W
	1TY1225-27A	200	0.1220	19.540	160.1	0.0105	-	-	-	14.97	-	-	1/2 W
	1TY1225-2G	200	0.1204	19,660	163.2	0.0100	-	-	-	15.52	-	-	1/2 W
	2TY1226-3B	200	0.1211	18,880	155.9	0.0098	-	-	-	15.58	-	-	-
	2TY1225-14A	275	0.1208	18,940	156.8	0.0106	-	-	-	14.69	-	-	1/2 W
	2TY1225-20A	275	0.1214	20,020	164.9	0.0124	-	-	-	14.92	-	-	G
	2TY1225-27A	275	0.1207	18,520	153.4	0.0104	-	-	-	15.15	-	-	G
67% - 0° Laminate L2 - Transverse $(90/45/90_2/-45/90_2/45/90_2/-45/90)_s$ W.R.T. Load	2TY1225-6C	-65	0.1217	2,510	20.5	0.0105	1746	14.35	0.0052	2.74	1.21	-	1/2 W
	2TY1225-5D	-65	0.1221	2,670	21.9	0.0115	1800	14.74	0.0053	2.76	1.19	-	W
	2TY1225-6E	-65	0.1220	2,630	26.6	b	1674	13.72	0.0051	2.69	1.33	-	W
	1TY1225-12E	72	0.1234	2,715	22.0	0.0112	1846	14.96	0.0059	2.73	1.18	0.087	W
	2TY1225-2E	72	0.1217	2,545	20.9	0.0100	1852	15.22	0.0058	2.77	1.21	0.279	W
	2TY1226-15D	72	0.1209	2,730	22.6	0.0112	1892	15.65	0.0055	2.87	1.25	0.107	W
	1TY1225-6F	200	0.1217	2,595	24.6	0.0096	2208	18.14	0.0065	2.78	0.94	-	G
	2TY1226-18D	200	0.1210	2,575	21.3	0.0109	2202	10.74	0.0068	2.68	0.81	-	1/2 W
	2TY1226-12E	200	0.1224	2,640	21.6	0.0109	2283	11.67	0.0072	2.63	0.98	-	W
	2TY1226-10E	275	0.1224	2,440	19.9	0.0105	1905	15.56	0.0063	2.51	1.13	-	G
	2TY1226-5F	275	0.1212	2,450	20.2	0.0098	1800	14.85	0.0061	2.46	1.46	-	G
	2TY1226-15F	275	0.1211	2,460	20.3	0.0103	1656	13.67	0.0052	2.64	1.33	-	G

a - G - gage section one inch from tabs. W - between 1/2 and 1 specimen width (1 inch) away from tab.
1/2 W - between tab end and 1/2 width from tab end.

b - Extensometer slipped, inaccurate reading.

TABLE 15b

TENSION TEST RESULTS FOR WET LAMINATE L2 - T300/5208

	Specimen ID	Test Temp. °C	Average Area mm^2	Ultimate Load P_{ult}, KN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm	Slope Deviation Load P_y, KN	Slope Deviation Stress σ_y, MPa	Slope Deviation Strain ϵ_y, mm/mm in 51 mm	Initial Apparent Modulus of Elasticity E_{ai}, GPa	Final Apparent Modulus of Elasticity E_{af}, GPa	Poisson's Ratio ν	Failure Location [a]
67% - 0° Laminate L2 - Longitudinal $(0/45/0_2/-45/0_2/45/0_2/-45/0)_s$ W.R.T. Load	1TY-1225-9A	-54	78.1	84.2	1076	0.0106	-	-	-	105	-	-	1/2 W
	1TY-1225-20A	-54	78.1	67.9	870	0.0089	-	-	-	101	-	-	1/2 W
	2TY-1226-8B	-54	78.1	88.9	1137	0.0117	-	-	-	97	-	-	1/2 W
	2TY-1225-14B	22	78.8	89.3	1133	0.0105	-	-	-	107	-	0.300	G
	2TY-1225-1G	22	77.9	92.8	1191	b	-	-	-	109	-	0.200	W
	2TY-1225-15B	22	78.4	82.3	1049	0.0096	-	-	-	110	-	0.175	1/2 W
	1TY-1225-27A	93	78.7	86.7	1104	0.0105	-	-	-	103	-	-	1/2 W
	1TY-1225-2G	93	77.7	87.4	1125	0.0100	-	-	-	107	-	-	1/2 W
	2TY-1226-3B	93	78.1	84.0	1075	0.0098	-	-	-	107	-	-	-
	2TY-1225-14A	135	77.9	84.2	1081	0.0106	-	-	-	101	-	-	1/2 W
	2TY-1225-20A	135	78.3	89.0	1136	0.0124	-	-	-	103	-	-	G
	2TY-1225-27A	135	77.9	82.4	1057	0.0104	-	-	-	104	-	-	G
67% - 0° Laminate L2 - Transverse $(90/45/90_2/-45/90_2/45/90_2/-45/90)_s$ W.R.T. Load	2TY-1225-6C	-54	78.5	11.2	142	0.0105	7.8	98	0.0052	18.9	8.3	-	1/2 W
	2TY-1225-5D	-54	78.8	11.9	151	0.0115	8.0	101	0.0053	19.0	8.2	-	W
	2TY-1225-6E	-54	78.7	11.7	183	b	7.4	94	0.0051	18.5	9.2	-	W
	1TY-1225-12E	22	79.6	12.1	152	0.0112	8.2	103	0.0059	18.8	8.1	0.087	W
	2TY-1225-2E	22	78.5	11.3	144	0.0100	8.2	105	0.0058	19.1	8.3	0.279	W
	2TY-1226-15D	22	78.0	12.1	156	0.0112	8.4	108	0.0055	19.8	8.6	0.107	W
	1TY-1225-6F	93	78.5	11.5	170	0.0096	9.8	125	0.0065	19.1	6.4	-	G
	2TY-1226-18D	93	78.0	11.4	147	0.0109	9.8	74	0.0068	18.5	5.6	-	1/2 W
	2TY-1226-12E	93	78.9	11.7	149	0.0109	10.1	80	0.0072	18.1	6.7	-	W
	2TY-1226-10E	135	79.0	10.8	137	0.0105	8.5	107	0.0063	17.3	7.89	-	G
	2TY-1226-5F	135	78.2	11.0	139	0.0098	8.0	102	0.0061	16.9	10.1	-	G
	2TY-1226-15F	135	78.1	10.9	140	0.0103	7.4	94	0.0052	18.2	9.2	-	G

a - G = gage section one inch from tabs. W = between 1/2 and 1 specimen width (1-inch) away from tab. 1/2 W = between tab end and 1/2 width from tab end.

b - Extensometer slipped, inaccurate reading.

TABLE 16a

TENSION TEST RESULTS FOR DRY LAMINATE U1 - T300/5208

	Specimen ID	Test Temp. °F	Average Area in.^{2}	Ultimate Load P_{ult}, lbs	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in.	E_a or[a] E_{s70}, psi x 10^6	Secondary Apparent Modulus of Elasticity E_b, psi x 10^6	Secant Modulus at Failure E_{sf}, psi x 10^6	Poisson's Ratio	Failure[b] Location
U1-L 0° Unidirectional	2TY1216-8A	-65	0.0804	13,200	164.2	0.0081	18.6	-	20.0	-	G
	1TY1218-11B	-65	0.0803	14,620	182.1	0.0090	20.1	-	20.2	-	G
	1TY1218-37B	-65	0.0799	13,980	175.0	0.0071	19.9	-	21.5	-	G
	2TY1216-10A	72	0.0808	15,720	194.6	0.0089	19.9	-	21.7	.181	1/2 W
	1TY1218-19B	72	0.0800	16,980	212.4	0.0102	19.0	23.5	21.1	-	1/2 W
	1TY1218-25B	72	0.0799	18,140	227.1	0.0102	20.6	-	22.3	.133	1/2 W
	1TY1218-29B	72	0.0796	15,920	200.0	0.0097	18.7	22.4	20.7	-	1/2 W
	1TY1218-31B	72	0.0797	17,200	215.9	0.0100	18.6	23.7	21.5	-	1/2 W
	1TY1218-38A	72	0.0799	10,420	130.4	0.0057	21.7	-	22.9	.230	1/2 W
	1TY1216-28A	200	0.0817	19,520	238.8	0.0123	19.1	22.5	19.3	-	1/2 W
	1TY1218-3A	200	0.0795	17,860	224.6	0.0100	18.9	25.0	22.4	-	1/2 W
	1TY1218-10A	200	0.0794	19,300	243.0	0.0115	21.3	-	-	-	1/2 W
	1TY1216-21A	275	0.0814	19,200	235.8	0.0122	18.2	22.0	19.3	-	1/2 W
	1TY1216-36A	275	0.0816	18,880	235.5	0.0139	19.1	23.2	21.0	-	1/2 W
	1TY1216-11B	275	0.0809	16,940	209.5	0.0102	22.5	-	-	-	1/2 W
	2TY1216-22A	275	0.0819	19,920	243.3	0.0139	20.4	21.7	18.6	-	1/2 W
	2TY1216-29A	275	0.0810	19,140	236.4	0.0131	19.9	23.8	18.2	-	1/2 W
	1TY1218-14A	275	0.0810	17,660	218.0	0.0107	19.8	23.4	20.1	-	1/2 W
U1-T 90° Unidirectional	1TY1216-11C	-65	0.0807	298	3.7	0.0022	1.58	-	-	-	1/2 W
	1TY1216-9D	-65	0.0816	356	4.4	0.0023	1.64	-	-	-	1/2 W
	1TY1216-1F	-65	0.0802	384	4.8	0.0032	1.48	-	-	-	1/2 W
	1TY1216-12C	72	0.0812	374	4.6	0.0036	1.28	-	-	-	1/2 W
	1TY1216-13D	72	0.0813	180	2.2	0.0016	1.38	-	-	-	1/2 W
	1TY1216-1,D	72	0.0824	433	5.3	0.0038	1.38	-	-	-	1/2 W
	1TY1216-1D	200	0.0804	288	3.6	0.0032	1.19	-	-	-	G
	1TY1218-2E	200	0.0806	322	4.0	0.0033	1.21	-	-	-	G
	1TY1218-10F	200	0.0817	380	4.7	0.0040	1.22	-	-	-	G
	1TY1216-4C	275	0.0805	394	4.9	0.0041	1.09	-	-	-	G
	1TY1216-8D	275	0.0817	232	2.8	0.0024	1.11	-	-	-	1/2 W
	1TY1218-8E	275	0.0814	402	4.9	0.0045	1.14	-	-	-	G

a - Secant Modulus E_{s70} at 70 ksi for U1-L; Initial Apparent Modulus, E_a for U1-T

b - G - gage section one inch from tabs. 1/2 W - between tab end and 1/2 width from tab end.

TABLE 16b

TENSION TEST RESULTS FOR DRY LAMINATE U1 - T300/5208

	Specimen ID	Test Temp. °C	Average Area mm^2	Ultimate Load P_{ult}, KN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm	E_a or E_{s70} GPa [a]	Secondary Apparent Modulus of Elasticity E_{bi}, GPa	Secant Modulus at Failure E_{sfi} GPa	Poisson's Ratio ν	Failure Location [b]
U1-L 0° Unidirectional	2TY-1216-8A	-54	51.9	58.7	1132	0.0081	128	-	137	-	G
	1TY-1218-11B	-54	51.8	65.0	1255	0.0090	138	-	139	-	G
	1TY-1218-37B	-54	51.5	62.2	1206	0.0071	137	-	148	-	G
	2TY-1216-10A	22	52.1	69.9	1339	0.0089	137	-	149	.181	1/2 W
	1TY-1218-19B	22	51.6	75.5	1464	0.0102	131	162	145	-	1/2 W
	1TY-1218-25B	22	51.5	80.7	1565	0.0102	142	-	154	.133	1/2 W
	1TY-1218-29B	22	51.3	70.8	1378	0.0097	129	154	143	-	1/2 W
	1TY-1218-31B	22	51.4	76.5	1488	0.0100	128	163	148	-	1/2 W
	1TY-1218-38A	22	51.5	46.3	899	0.0057	149	-	158	.230	1/2 W
	1TY-1216-28A	93	52.7	86.8	1646	0.0123	132	155	133	-	1/2 W
	1TY-1216-3A	93	51.3	79.4	1548	0.0100	130	172	145	-	1/2 W
	1TY-1216-10A	93	51.2	85.8	1675	0.0115	147	-	-	-	1/2 W
	1TY-1216-21A	135	52.5	85.4	1625	0.0122	125	151	133	-	1/2 W
	1TY-1216-36A	135	52.6	84.0	1624	0.0139	132	159	145	-	1/2 W
	1TY-1216-11B	135	52.2	75.3	1444	0.0102	155	-	-	-	1/2 W
	2TY-1216-22A	135	52.8	88.6	1677	0.0139	141	149	128	-	1/2 W
	2TY-1216-29A	135	52.2	85.1	1630	0.0131	137	164	125	-	1/2 W
	1TY-1218-14A	135	52.2	78.5	1503	0.0107	136	161	138	-	1/2 W
U1-T 90° Unidirectional	1TY-1216-11C	-54	52.1	1.3	25.5	0.0022	10.9	-	-	-	1/2 W
	1TY-1216-9D	-54	52.6	1.6	30.3	0.0023	11.3	-	-	-	1/2 W
	1TY-1216-1F	-54	51.7	1.7	33.1	0.0032	10.2	-	-	-	1/2 W
	1TY-1216-12C	22	52.4	1.7	31.7	0.0036	8.8	-	-	-	1/2 W
	1TY-1216-13D	22	52.4	0.8	15.2	0.0016	9.5	-	-	-	1/2 W
	1TY-1216-15D	22	53.2	1.9	36.5	0.0038	9.5	-	-	-	1/2 W
	1TY-1216-1D	93	51.8	1.3	24.8	0.0032	8.2	-	-	-	G
	1TY-1216-2E	93	52.0	1.4	27.5	0.0033	8.3	-	-	-	G
	1TY-1216-10F	93	53.0	1.7	32.4	0.0040	8.4	-	-	-	G
	1TY-1216-4C	135	52.0	1.7	33.8	0.0041	7.5	-	-	-	G
	1TY-1216-8D	135	53.0	1.0	19.3	0.0024	7.6	-	-	-	1/2 W
	1TY-1216-8E	135	52.5	1.8	33.8	0.0045	7.8	-	-	-	G

a - Secant Modulus E_{s70} at 70 ksi for U1-L; Initial Apparent Modulus, E_a for U1-T

b - G = gage section one inch from tabs. 1/2 W = between tab end and 1/2 width from tab end.

TABLE 17a

TENSION TEST RESULTS FOR WET LAMINATE U1 - T300/5208

	Specimen ID	Test Temp. °F	Average Area in.^{2}	Ultimate Load P_{ult}, lbs	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in.	Initial Apparent Modulus of Elasticity E_a, psi x 10^6	Poisson's Ratio	Failure Location[a]
U1-L 0° Unidirectional	1TY-1216-2A	-65	0.0811	19,700	242.9	0.0101	21.2[b]	-	G
	1TY-1218-37A	-65	0.0795	17,700	222.6	0.0084	22.6[b]	-	G
	1TY-1218-9B	-65	0.0792	15,400	194.4	0.0085	21.2[b]	-	G
	2TY-1216-9A	72	0.0805	19,400	241.0	0.0108	20.7	0.133	S
	1TY-1218-32B	72	0.0807	18,200	225.5	0.0102	21.4	0.138	S
	1TY-1218-38B	72	0.0796	19,700	247.5	0.0111	20.9	0.083	S
	1TY-1216-12B	200	0.0817	18,600	227.7	0.0107	20.2	-	1/2 W
	1TY-1218-11A	200	0.0807	18,625	230.8	0.0093	22.6	-	1/2 W
	1TY-1218-13B	200	0.0792	18,350	231.7	0.0094	22.3	-	1/2 W
	1TY-1216-23A	275	0.0817	19,700	241.1	0.0100	22.9	-	S
	1TY-1216-27A	275	0.0804	18,000	223.9	0.0090	24.9	-	S
	1TY-1218-18B	275	0.0786	20,550	261.5	0.0110	23.3	-	S
U1-T 90° Unidirectional	1TY-1216-17C	-65	0.0814	194	2.4	0.0012	1.7	-	1/2 W
	2TY-1216-12D	-65	0.0814	137	1.7	0.0009	1.8	-	1/2 W
	2TY-1216-5F	-65	0.0799	177	2.2	0.0016	1.4	-	1/2 W
	1TY-1216-14C	72	0.0811	-	-	-	-	-	-
	1TY-1216-14E	72	0.0817	192	2.4	0.0019	1.3	-	1/2 W
	2TY-1216-9D	72	0.0816	260	3.2	0.0024	1.3	-	1/2 W
	1TY-1216-7C	200	0.0814	198	2.4	0.0023	1.1	-	G
	1TY-1216-15C	200	0.0815	30	0.4	-	-	-	1/2 W
	1TY-1216-2F	200	0.0801	197	2.5	0.0021	1.2	-	G
	1TY-1216-10C	275	0.0815	107	1.3	0.0017	0.8	-	1/2 W
	1TY-1216-18E	275	0.0821	131	1.6	-	-	-	1/2 W
	2TY-1216-16C	275	0.0795	122	1.5	0.0017	0.9	-	1/2 W

a - G - gage section one inch from tabs. 1/2W - between tab end and 1/2 width from tab end.

S - Shattered.

b - Secant Modulus E_{s70} at 70 ksi, E_b and E_{sf} are, respectively: 24.9, 24.1; 30.9, 26.5; 24.3, 22.8

TABLE 17b

TENSION TEST RESULTS FOR WET LAMINATE U1 - T300/5208

	Specimen ID	Test Temp. °C	Average Area mm^2	Ultimate Load P_{ult}, KN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm	Initial Apparent Modulus of Elasticity E_{ai}, GPa	Poisson's Ratio	Failure Location [a]
U1-L 0° Unidirectional	1TY-1216-2A	-54	52.3	87.6	1675	0.0101	146[b]	-	G
	1TY-1218-37A	-54	51.3	78.7	1535	0.0084	156[b]	-	G
	1TY-1218-9B	-54	51.1	68.5	1340	0.0085	146[b]	-	G
	2TY-1216-9A	22	51.9	86.3	1661	0.0108	143	0.133	S
	1TY-1218-32B	22	52.1	80.9	1555	0.0102	147	0.138	S
	1TY-1218-38B	22	51.3	87.6	1706	0.0111	144	0.083	S
	1TY-1216-12B	93	52.7	82.7	1570	0.0107	139	-	1/2 W
	1TY-1218-11A	93	52.1	82.8	1591	0.0093	156	-	1/2 W
	1TY-1218-13B	93	51.1	81.6	1597	0.0094	154	-	1/2 W
	1TY-1216-23A	135	52.7	87.6	1662	0.0100	158	-	S
	1TY-1216-27A	135	51.9	80.1	1544	0.0090	171	-	S
	1TY-1218-18B	135	50.7	91.4	1803	0.0110	161	-	S
U1-T 90° Unidirectional	1TY-1216-17C	-54	52.5	0.86	16.5	0.0012	11.7	-	1/2 W
	2TY-1216-12D	-54	52.5	0.61	11.7	0.0009	12.4	-	1/2 W
	2TY-1216-5F	-54	51.5	0.78	15.2	0.0016	9.6	-	1/2 W
	1TY-1216-14C	22	52.3	-	-	-	-	-	-
	1TY-1216-14E	22	52.7	0.85	16.5	0.0019	9.0	-	1/2 W
	2TY-1216-9D	22	52.6	1.15	22.1	0.0024	9.0	-	1/2 W
	1TY-1216-7C	93	52.5	0.88	16.5	0.0023	7.6	-	G
	1TY-1216-15C	93	52.6	0.13	2.7	-	-	-	1/2 W
	1TY-1216-2F	93	51.7	0.87	17.2	0.0021	8.3	-	G
	1TY-1216-10C	135	52.6	0.47	8.9	0.0017	5.5	-	1/2 W
	1TY-1216-18E	135	53.0	0.58	11.0	-	-	-	1/2 W
	2TY-1216-16C	135	51.3	0.54	10.3	0.0017	6.2	-	1/2 W

a - G = gage section one inch from tab. 1/2 W = between tab end and 1/2 width from tab end.

S = Shattered

b - Secant Modulus E_{s70} at 70 ksi, E_b and E_{sf} are, respectively: 172, 166; 213, 183; 168, 157

TABLE 18a

TENSION TEST RESULTS FOR DRY AND WET LAMINATE L1 - A-S/3501-5A

	Specimen ID	Test Temp. °F[a]	Average Area in.^{2}	Ultimate Load P_{ult}, lbs	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in.	Slope Deviation Load P_y, lbs	Slope Deviation Stress σ_y, ksi	Slope Deviation Strain, ϵ_y, in./in. in 2 in.	Initial Apparent Modulus of Elasticity E_{ai}, psi x 10^6	Final Apparent Modulus of Elasticity E_{af}, psi x 10^6	Poisson's Ratio ν	Failure Location[b]
Quasi-Isotropic Laminate L1 - Longitudinal $(0/45/90/-45_2/90/45/0)_s$ W.R.T. Load	1TJ1282-7B	72D	0.0868	6850	78.9	0.0112	4860	55.0	0.0077	7.50	6.51	0.157	G
	1TJ1282-23B	72D	0.0845	7130	84.4	0.0123	4000	47.3	0.0068	7.23	6.38	0.151	G
	1TJ1282-18C	72D	0.0868	7450	85.8	0.0125	5650	65.1	0.0092	7.26	6.65	0.150	G
	1TJ1282-6A	275W	0.0848	7300	86.1	-	-	-	-	6.15	-	-	W
	1TJ1282-18A	275W	0.0877	6300	71.8	0.0121	-	-	-	6.04	-	-	G
	1TJ1282-19C	275W	0.0864	6280	72.7	-	-	-	-	6.14	-	-	G
Quasi-Isotropic Laminate L1 - Transverse $(90/45/0/-45_2/0/45/90)_s$ W.R.T. Load	1TJ1282-7E	72D	0.0864	7420	85.9	0.0120	3500	40.5	0.0055	7.66	7.23	0.137	G
	1TJ1282-16E	72D	0.0864	7140	82.6	0.0114	5060	58.6	0.0078	7.66	6.98	0.163	G
	1TJ1282-18E	72D	0.0842	7260	86.2	0.0130	4550	54.0	0.0078	6.93	6.64	0.158	G
	1TJ1282-7D	275W	0.0864	5940	68.7	0.0116	3600	41.6	0.0064	5.69	5.75	-	G
	1TJ1282-8E	275W	0.0864	6240	72.2	0.0174	2850	32.9	0.0049	5.51	5.47	-	G
	1TJ1282-11E	275W	0.0855	5480	64.1	-	-	-	-	6.04	-	-	G

a - D = Dry. W = Wet.

b - G - gage section one inch from tabs. W - between 1/2 and 1 specimen width (1-inch) away from tab.

TABLE 18b

TENSION TEST RESULTS FOR DRY AND WET LAMINATE L1 - A-S/3501-5A

	Specimen ID	Test Temp. °C [a]	Average Area mm^2	Ultimate Load P_{ult}, KN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm	Slope Deviation Load P_y, KN	Slope Deviation Stress σ_y, MPa	Slope Deviation Strain ϵ_y, mm/mm in 51 mm	Initial Apparent Modulus of Elasticity E_{ai}, GPa	Final Apparent Modulus of Elasticity E_{af}, GPa	Poisson's Ratio ν	Failure Location [b]
Quasi-Isotropic Laminate L1 - Longitudinal $(0/45/90/-45_2/90/45/0)_s$ W.R. T. Load	1TJ-1282-7B	22D	56.0	30.4	544	0.0112	21.6	379	0.0077	52	45	0.157	G
	1TJ-1282-23B	22D	54.5	31.7	582	0.0123	27.6	326	0.0068	50	44	0.151	G
	1TJ-1282-18C	22D	56.0	33.1	591	0.0125	25.1	449	0.0092	50	46	0.150	G
	1TJ-1282-6A	135W	54.7	32.5	594	-	-	-	-	42	-	-	W
	1TJ-1282-18A	135W	56.6	28.0	495	0.0121	-	-	-	42	-	-	G
	1TJ-1282-19C	135W	55.7	28.0	501	-	-	-	-	42	-	-	G
Quasi-Isotropic Laminate L1 - Transverse $(90/45/0/-45_2/0/45/90)_s$ W.R.T. Load	1TJ-1282-7E	22D	55.7	33.0	592	0.0120	15.6	379	0.0055	53	50	0.137	G
	1TJ-1282-16E	22D	55.7	31.7	569	0.0114	22.5	404	0.0078	53	48	0.163	G
	1TJ-1282-18E	22D	54.3	32.3	594	0.0130	20.2	372	0.0078	48	46	0.158	G
	1TJ-1282-7D	135W	55.7	26.4	473	0.0116	16.0	287	0.0064	39	40	-	G
	1TJ-1282-8E	135W	55.7	27.7	498	0.0174	12.6	227	0.0049	38	38	-	G
	1TJ-1282-11E	135W	55.1	24.4	442	-	-	-	-	42	-	-	G

a - D = Dry. W = Wet.

b - G = gage section one inch from tabs. W = between 1/2 and 1 specimen width (1-inch) away from tab

TABLE 19a

TENSION TEST RESULTS FOR DRY AND WET LAMINATE L2 - A-S/3501

	Specimen ID	Test Temp. °F[a]	Average Area in.^{2}	Ultimate Load P_{ult}, lbs	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in.	Slope Deviation Load P_y, lbs	Slope Deviation Stress σ_y, ksi	Slope Deviation Strain ϵ_y, in./in. in 2 in.	Initial Apparent Modulus of Elasticity E_{ai}, psi x 10^7	Final Apparent Modulus of Elasticity E_{af}, psi x 10^6	Failure[b] Location
67% - 0° Laminate L2 - Longitudinal $(0/45/0_2/-45/0_2/45/0_2/-45/0)_s$ W.R.T. Load	1TY1240-5B	72D	0.1262	19,300	152.9	0.0107	-	-	-	13.5	-	G
	1TJ1245-2B	72D	0.1223	19,400	158.6	0.0110	-	-	-	14.1	-	G
	1TJ1283-1C	72D	0.1147	13,300	116.0	0.0093	-	-	-	13.0	-	1/2 W
	1TJ1283-1B	275W	0.1092	16,960	155.3	-	-	-	-	12.5	-	G
	1TJ1283-14B	275W	0.1243	18,720	150.7	0.0173	-	-	-	14.1	-	G
	1TJ1283-3C	275W	0.1282	19,240	150.1	-	-	-	-	12.6	-	G
67% - 0° Laminate L2 - Transverse $(90/45/90_2/-45/90_2/45/90_2/-45/90)_s$ W.R.T. Load	1TJ1283-15D	72D	0.1266	2,920	23.1	0.0140	2475	19.5	0.0079	2.5	0.76	W
	1TY1283-11E	72D	0.1268	3,030	23.9	0.0141	1775	14.0	0.0054	2.6	0.86	G
	2TY1283-4B	72D	0.1242	2,850	22.9	0.0159	2150	17.3	0.0064	2.6	0.76	G
	1TJ1283-9D	275W	0.1273	2,115	16.6	0.0141	-	-	-	1.4	-	W
	1TJ1283-2E	275W	0.1241	1,985	16.0	-	-	-	-	1.4	-	G
	1TJ1283-13E	275W	0.1240	1,990	16.1	-	-	-	-	1.4	-	G

a - D = Dry. W = Wet.

b - G = gage section one inch from tabs. W = between 1/2 and 1 specimen width (1-inch) away from tab.
1/2 W = between tab end and 1/2 width from tab end.

TABLE 19 b

TENSION TEST RESULTS FOR DRY AND WET LAMINATE L2 - A-S/3501

	Specimen ID	Test Temp. °C [a]	Average Area mm^2	Ultimate Load P_{ult}, KN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm	Slope Deviation Load P_y, KN	Slope Deviation Stress σ_y, MPa	Slope Deviation Strain ϵ_y, mm/mm in 51 mm	Initial Apparent Modulus of Elasticity E_{ai}, GPa	Final Apparent Modulus of Elasticity E_{af}, GPa	Poisson's Ratio ν	Failure Location [b]
67% -0° Laminate L2 - Longitudinal $(0/45/0_2/-45/0_2/45/0_2/-45/0)_s$ W.R.T. Load	1TJ-1240-5B	22D	81.4	85.8	1054	0.0107	-	-	-	93	-	-	G
	1TJ-1245-2B	22D	78.9	86.3	1093	0.0110	-	-	-	97	-	-	G
	1TJ-1283-1C	22D	74.0	59.2	800	0.0093	-	-	-	89	-	-	1/2 W
	1TJ-1283-1B	135W	70.4	75.4	1070	-	-	-	-	86	-	-	G
	1TJ-1283-14B	135W	80.2	83.3	1039	0.0107	-	-	-	97	-	-	G
	1TJ-1283-3C	135W	82.7	85.6	1035	-	-	-	-	87	-	-	G
67% - 0° Laminate L2 - Transverse $(90/45/90_2/-45/90_2/45/90_2/-45/90)_s$ W.R.T. Load	1TJ-1283-15D	22D	81.7	13.0	159	0.0140	11.0	134	0.0079	17	5.2	-	W
	1TY-1283-11E	22D	81.8	13.5	163	0.0141	7.9	96	0.0054	18	6.0	-	G
	2TY-1283-4B	22D	80.1	12.7	158	0.0159	9.5	119	0.0064	18	5.2	-	G
	1TJ-1283-9D	275W	82.1	9.4	114	0.014[illegible]	-	-	-	10	-	-	W
	1TJ-1283-2E	275W	80.1	8.8	110	-	-	-	-	10	-	-	G
	1TJ-1283-13E	275W	80.0	8.8	111	-	-	-	-	10	-	-	G

a - D = Dry. W = Wet.

b - G = gage section one inch from tabs. W = between 1/2 and 1 specimen width (1-inch) away from tab.
1/2 W = between tab end and 1/2 width from tab end.

TABLE 20a

TENSION TEST RESULTS FOR DRY AND WET LAMINATE U1 - A-S/3501

	Specimen ID	Test Temp,[a] °F	Average Area in.^{2}	Ultimate Load P_{ult}, lbs	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in.	Initial Apparent Modulus of Elasticity E_{ai}, psi x 10^6	Final Apparent Modulus of Elasticity E_{af}, psi x 10^6	Poisson's Ratio ν	Failure[b] Location
U1-L 0° Unidirectional	2TJ1281-9A	72D	0.0828	18,850	227.7	0.0102	22.3	-	0.113	S
	2TJ1281-16A	72D	0.0796	18,000	226.1	0.0108	20.9	-	0.115	S
	2TJ1281-3B	72D	0.0829	15,650	188.8	0.0094	20.1	-	0.100	S
	2TJ1281-23A	275W	0.0809	19,300	238.6	0.0118	21.1	-	-	S
	2TJ1281-5B	275W	0.0807	17,450	216.3	0.0112	22.7	-	-	S
	2TJ1281-6B	275W	0.0823	18,900	229.6	0.0104	22.8	-	-	S
U1-T 90° Unidirectional	2TJ1281-C19	72D	0.0818	c	-	-	-	-	-	-
	2TJ1281-C21	72D	0.0820	c	-	-	-	-	-	-
	2TJ1281-D4	72D	0.0817	300	3.7	0.0026	1.5	-	-	1/2 W
	2TJ1281-8C	275W	0.0820	98	1.2	0.0026	0.5	-	-	G
	2TJ1281-13C	275W	0.0817	10	0.1	-	-	-	-	1/2 W
	2TJ1281-21D	275W	0.0826	8	0.1	-	-	-	-	1/2 W

a - D = Dry. W = Wet.

b - G = gage section one inch from tabs. 1/2 W = between tab end and 1/2 width from tab end.
S = shattered.

c - Failure during loading.

TABLE 20b

TENSION TEST RESULTS FOR DRY AND WET LAMINATE U1 - A-S/3501

	Specimen ID	Test Temp. °C [a]	Average Area mm^2	Ultimate Load P_{ult}, KN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain, ϵ_{ult}, mm/mm	Initial Apparent Modulus of Elasticity E_{ai}, GPa	Final Apparent Modulus of Elasticity E_{af}, GPa	Poisson's Ratio ν	Failure Location [b]
U1-L 0° Unidirectional	2TJ-1281-9A	22D	53.4	83.8	1570	0.0102	154	-	0.113	S
	2TJ-1281-16A	22D	51.3	80.1	1559	0.0108	144	-	0.115	S
	2TJ-1281-3B	22D	53.4	69.6	1302	0.0094	138	-	0.100	S
	2TJ-1281-23A	135W	52.2	85.8	1645	0.0118	145	-	-	S
	2TJ-1281-5B	135W	52.1	77.6	1491	0.0112	156	-	-	S
	2TJ-1281-6B	135W	53.1	84.1	1583	0.0104	157	-	-	S
U1-T 90° Unidirectional	2TJ-1821-C19	22D	52.8	c	-	-	-	-	-	-
	2TJ-1821-C21	22D	52.9	c	-	-	-	-	-	-
	2TJ-1821-D4	22D	52.7	1.3	25.5	0.0026	10.3	-	-	1/2 W
	2TJ-1281-8C	135W	52.9	0.4	8.3	0.0026	3.4	-	-	G
	2TJ-1281-13C	135W	52.7	0.04	0.7	-	-	-	-	1/2 W
	2TJ-1281-21D	135W	53.3	0.03	0.7	-	-	-	-	1/2 W

a - D = Dry. W = Wet.

b - G = gage section one inch from tabs. 1/2 W = between tab end and 1/2 width from tab end.

S = Shattered.

c - Failure during loading.

TABLE 21

TENSION DATA SUMMARY FOR DRY T300/5208

Laminate Type	Test Temperature °F	Test Temperature °C	Average Ultimate Stress ksi	Average Ultimate Stress MPa	Average Ultimate Strain in/in	Average Ultimate Strain mm/mm	Average Initial Apparent Modulus of Elasticity psi x 10^6	Average Initial Apparent Modulus of Elasticity GPa	Average Final Apparent Modulus of Elasticity psi x 10^6	Average Final Apparent Modulus of Elasticity GPa	Poisson's Ratio
L1	-65	-54	67.8	467	0.0089	0.0089	7.69	53.0	6.74	46.5	-
Longitud-	72	22	76.4	526	0.0105	0.0105	7.59	52.3	6.47	44.6	0.273
inal	200	93	72.5	500	0.0099	0.0099	7.51	51.8	-	-	-
	275	135	76.3	526	0.0102	0.0102	7.48	51.6	-	-	-
L1	-65	-54	68.7	474	0.0087	0.0087	7.86	54.2	-	-	-
Trans-	72	22	77.8	536	0.0106	0.0106	7.54	52.0	7.06	48.7	0.273
verse	200	93	73.9	509	0.0108	0.0108	7.26	50.0	-	-	-
	275	135	69.1	476	0.0108	0.0108	7.47	51.5	-	-	-
L2	-65	-54	152.8	1053	0.0097	0.0097	15.10	104.1	-	-	-
Longitud-	72	22	149.4	1031	0.0100	0.0100	14.75	101.7	-	-	0.569
inal	200	93	162.5	1120	0.0110	0.0110	14.69	101.3	-	-	-
	275	135	158.1	1090	0.0105	0.0105	13.83	95.3	-	-	-
L2	-65	-54	21.0	145	0.0123	0.0123	2.66	18.3	0.63	4.34	-
Trans-	72	22	20.3	140	0.0102	0.0102	2.47	17.0	0.91	6.27	0.035
verse	200	93	21.0	145	0.0117	0.0117	2.51	17.3	0.99	6.82	-
	275	135	21.4	147	0.0104	0.0104	2.58	17.8	1.[illegible]3	8.48	-
U1	-65	-54	173.8	1198	0.0081	0.0081	19.5	134.4	20.6	142.0	-
Longitud-	72	22	196.7	1356	0.0091	0.0091	19.7	135.8	21.7	149.6	0.181
inal	200	93	235.5	1623	0.0112	0.0112	19.8	136.5	20.8	136.5	-
	275	135	229.7	1583	0.0122	0.0122	20.0	137.9	19.4	137.9	-
U1	-65	-54	4.3	30	0.0026	0.0026	1.57	10.8	-	-	-
Trans-	72	22	4.0	28	0.0030	0.0030	1.35	9.3	-	-	-
verse	200	93	4.1	28	0.0035	0.0035	1.21	8.3	-	-	-
	275	135	4.2	29	0.0037	0.0037	1.11	7.6	-	-	-

TABLE 22

TENSION DATA SUMMARY FOR WET T300/5208

Laminate Type	Test Temperature °F	°C	Average Ultimate Stress ksi	MPa	Average Ultimate Strain in/in	mm/mm	Average Initial Apparent Modulus of Elasticity psi x 10^6	GPa	Average Final Apparent Modulus of Elasticity psi x 10^6	GPa	Poisson's Ratio
L1 Longitudinal	-65	-54	74.4	513	0.0099	0.0099	7.78	53.6	5.97	39.9	-
	72	22	79.7	549	0.0100	0.0100	7.84	54.0	-	-	0.220
	200	93	78.3	540	0.0102	0.0102	7.85	54.1	-	-	-
	275	135	74.3	512	0.0114	0.0114	6.83	47.1	5.17	35.6	-
L1 Transverse.	-65	-54	74.6	514	0.0101	0.0101	7.45	51.3	-	-	-
	72	22	79.7	549	0.0105	0.0105	7.62	52.5	-	-	0.300
	200	93	74.3	512	0.0102	0.0102	7.57	52.2	-	-	-
	275	135	71.9	496	0.0102	0.0102	7.23	49.8	-	-	-
L2 Longitudinal	-65	-54	149.1	1028	0.0371	0.0371	14.64	100.9	-	-	-
	72	22	163.0	1124	0.0100	0.0100	15.75	108.6	-	-	-
	200	93	159.7	1101	0.0101	0.0101	15.36	105.9	-	-	-
	275	135	158.3	1091	0.0111	0.0111	14.92	102.9	-	-	-
L2 Transverse	-65	-54	23.0	158	0.0110	0.0110	2.73	18.8	1.24	8.5	-
	72	22	21.8	150	0.0108	0.0108	2.79	19.2	1.21	8.3	0.158
	200	93	22.5	155	0.0105	0.0105	2.70	18.6	0.91	6.3	-
	275	135	20.1	138	0.0102	0.0102	2.54	17.5	1.31	9.0	-
U1 Longitudinal	-65	-54	219.9	1516	0.0090	0.0090	21.7	149.6	-	-	-
	75	22	238.0	1640	0.0107	0.0107	21.0	144.8	-	-	0.118
	200	93	230.1	1586	0.0098	0.0098	21.7	149.6	-	-	-
	275	135	242.2	1670	0.0100	0.0100	23.7	163.4	-	-	-
U1 Transverse	-65	-54	2.1	14	0.0012	0.0012	1.6	11.0	-	-	-
	75	22	2.8	19	0.0021	0.0021	1.3	9.0	-	-	-
	200	93	1.8	12	0.0022	0.0022	1.1	7.6	-	-	-
	275	135	1.5	10	0.0017	0.0017	0.8	5.5	-	-	-

TABLE 23

TENSION DATA SUMMARY FOR DRY AND WET AS/3501-5A

Laminate Type	Test Temperature °F	°C	Average Ultimate Stress ksi	MPa	Average Ultimate Strain in/in	mm/mm	Average Initial Apparent Modulus of Elasticity psi x 10^6	GPa	Average Final Apparent Modulus of Elasticity psi x 10^6	GPa	Poisson's Ratio
L1 Longitud-inal	72D	22	83.0	572	0.0120	0.0120	7.33	50.5	6.51	44.9	0.153
	275W	135	76.9	530	0.0121	0.0121	6.11	42.1	-	-	-
L1 Trans-verse	72D	22	84.9	585	0.0121	0.0121	7.42	51.1	6.95	47.9	0.153
	275W	135	68.3	471	0.0145	0.0145	5.75	39.6	5.61	38.7	-
L2 Longitud-inal	72D	22	142.5	982	0.0103	0.0103	13.5	93.1	-	-	-
	275W	135	152.0	1048	0.0173	0.0173	13.1	90.3	-	-	-
L2 Trans-verse	72D	22	23.3	161	0.0146	0.0146	2.6	17.9	0.79	5.4	-
	275W	135	16.2	112	0.0141	0.0141	1.4	9.6	-	-	-
U1 Longitud-inal	72D	22	214.2	1477	0.0101	0.0101	21.1	145.5	-	-	0.109
	275W	135	228.2	1573	0.0111	0.0111	22.2	153.1	-	-	-
U1 Trans-	72D	22	3.7	25	0.0026	0.0026	1.5	8.3	-	-	-
	275W	135	0.4	2	0.0026	0.0026	0.5	3.4	-	-	-

side. Delamination and splitting was markedly less in the L2L coupons, the failure zone being localized and the fracture jagged, at a slight angle to the load. Transverse tests of both laminates exhibited highly localized failures running straight across the section, accompanied by almost no splitting or delamination.

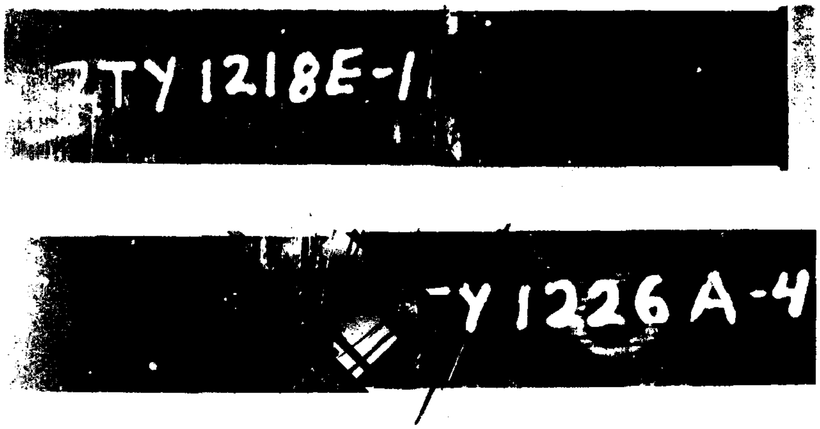
- At -54°C (-65°F), all failures were similar to those at room temperature with the exception of those in L2L coupons, in which all plies failed at a 45° angle. At elevated temperature, the failures, also with one exception, were similar to those at room temperature, with possibly a slight increased amount of delamination and splitting. The exception was again L2L, which exhibited considerably more delamination and splitting at elevated temperature.

Typical failures are displayed in Figures 59 through 64.

4.5 In-Plane Shear Test

Static tension tests of ±45° specimens were conducted in a 267 KN (60 kip) Baldwin universal test machine. Specimen dimensions, gripping and alignment procedures were the same as for static tension tests described in Section 4.4. Specimens were instrumented with "T" type strain gages with an axial and lateral element at 0° and 90°, respectively. Load-strain data were processed to shear stress-strain data by use of a computer program which is based on ASTM D 3518-76, "In-Plane Shear Stress-Strain Response of Unidirectional Reinforced Plastics".

For both materials, three replicates were tested at each condition. Specimens of the T300/5208 material were tested at four temperatures after either the "dry" or the "wet" environmental conditioning treatment described in Section 4.3. AS/3501-5A specimens were tested at 22°C (72°F) after dry conditioning and at 135°C (275°F) after wet conditioning. Test results are summarized in Tables 24 and 25. Since the shear stress vs. strain response is non-linear, the in-plane shear modulus G_{12} was evaluated at both the initial linear portion of the curve and at 138 MPa (20 ksi). This latter value is designated G_{12} in the tables. Representative in-plane shear stress-shear strain curves for the different materials and test conditions are presented in Figures 65 through 74.



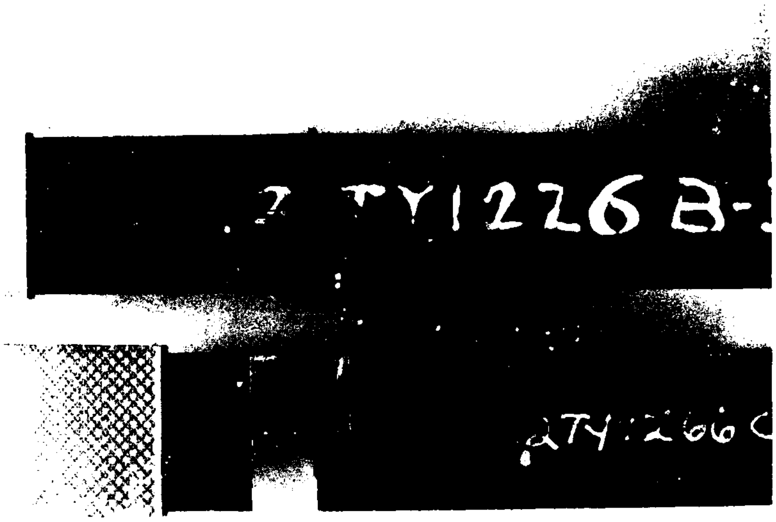
139 096R

a. Side view, coupons 2TY1218-11E (L1T) and 1TY1226-4A (L1L)

139 081R

b. Edge view, coupons 2TY1218-11E (L1T) and 1TY1226-4A (L1L)

Figure 59. - Representative coupons failed in static tension at -54°C (-65°F) after conditioning at 22°C (72°F)/40% RH.



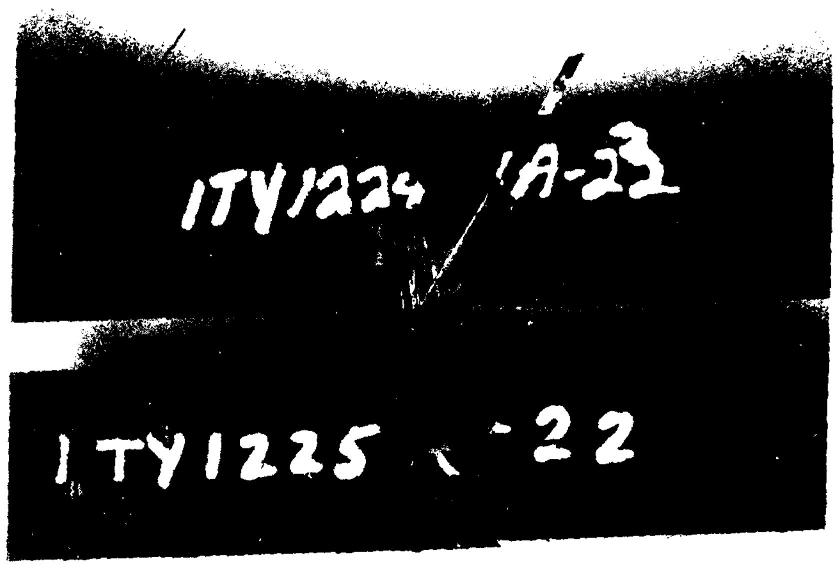
139 089R

a. Side view, coupons 2TY1226-35B (L2L) and 2TY1226-11C (L2T)

139 080R

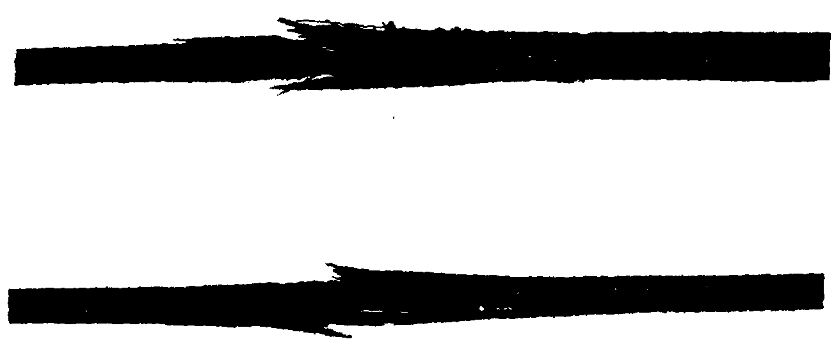
b. Edge view, coupons 2TY1226-35B (L2L) and 2TY1226-11C (L2T)

Figure 60. - Representative coupons failed in static tension at -54°C (-65°F) after conditioning at 22°C (72°F)/40% RH.



139 090R

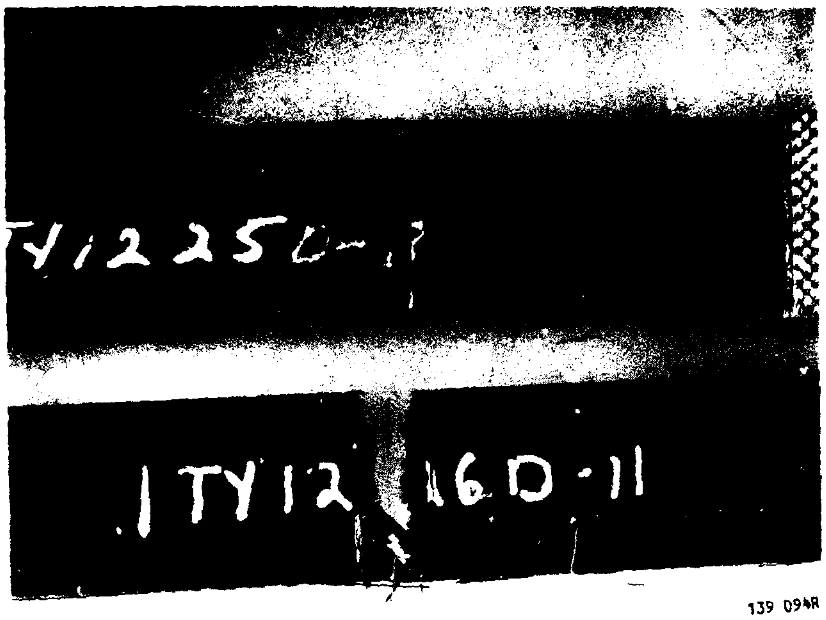
a. Side view, coupons 1TY1224-23A (L1L) and 1TY1225-22A (L2L)



139 085R

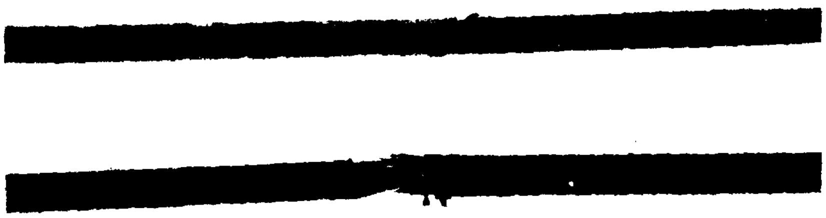
b. Edge view, coupons 1TY1224-23A (L1L) and 1TY1225-22A (L2L)

Figure 61. - Representative coupons failed in static tension at 22°C (72°F) after conditioning at 22°C (72°F)/40% RH.



139 094R

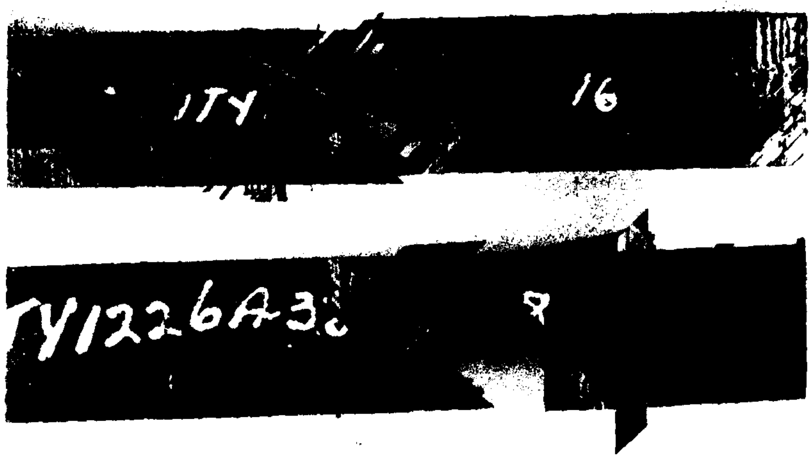
a. Side view, coupons 2TY1225-8D (L2T) and 1TY1226-11D (L1T)



139 084R

b. Edge view, coupons 2TY1225-8D (L2T) and 1TY1226-11D (L1T)

Figure 62. - Representative coupons failed in static tension at 22°C (72°F) after conditioning at 22°C (72°F)/40% RH.



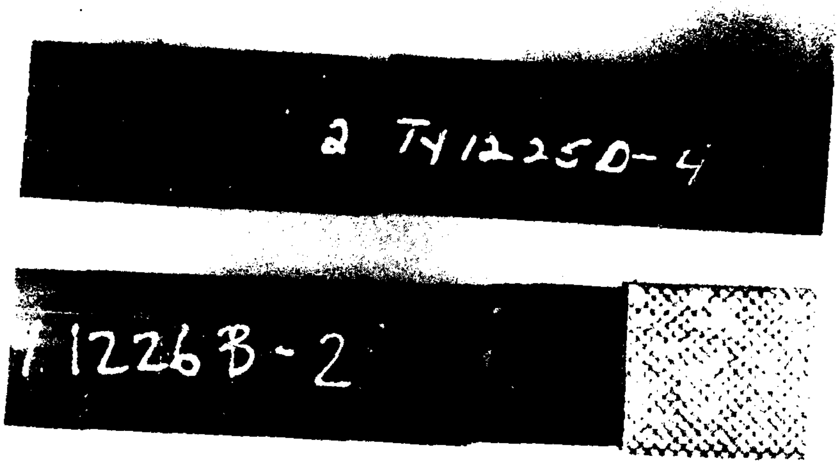
139 098R

a. Side view, coupons 1TY1226-16F (L1T) and 1TY1226-38A (L1L)

139 082R

b. Edge view, coupons 1TY1226-16F (L1T) and 1TY1226-38A (L1L)

Figure 63. - Representative coupons failed in static tension at 93°C (200°F) after conditioning at 22°C (72°F)/40% RH.



139 097R

a. Side view, coupons 2TY1225-4D (L2T) and 2TY1226-2B (L2L)

139 083R

b. Edge view, coupons 2TY1225-4D (L2T) and 2TY1226-2B (L2L)

Figure 64. - Representative coupons failed in static tension at 93°C (200°F) after conditioning at 22°C (72°F)/40% RH.

TABLE 24a

IN-PLANE SHEAR (±45° TENSION) TEST RESULTS FOR DRY, T300/5208 MATERIAL

Specimen ID	Temperature °C	Temperature °F	Area mm^2	Area $in.^2$	P_{ult}, kN	P_{ult}, kip	σ_{ult}, MPa	σ_{ult}, ksi	$\epsilon_{long_{max}}$	$\epsilon_{lat_{max}}$	ν	τ_{max}, MPa	τ_{max}, ksi	δ_{max}	G_{12} GPa	G_{12} psi x 10^6	G'_{12} psi x 10^6
1TY-1227-1[illegible]A	-54	-65	53.0	0.0821	10.2	2.29	191	27.[illegible]	0.0124	-0.0098	0.727	96.5	14.[illegible]	0.0222	5.9	0.86	.37
1TY-1227-17B	-54	-65	52.8	0.0819	10.4	2.34	196	28.4	0.0124	-0.0096	0.688	101.0	14.7	0.0220	4.7	0.68	.28
1TY-1227-18B	-54	-65	52.9	0.0820	10.4	2.33	194	28.2	0.0138	-0.0105	0.676	97.9	14.2	0.0244	5.9	0.86	.33
1TY-1227-4A	22	72	52.8	0.0819	9.03	2.03	171	24.8	0.0160	-0.0182	1.32	85.5	12.4	0.0342	5.5	0.80	.23
1TY-1227-15A	22	72	53.0	0.0822	9.12	2.05	172	24.9	0.0187	a	1.03	85.5	12.4	a	5.1	0.74	.24
1TY-1227-25A	22	72	52.2	0.0809	9.25	2.08	177	25.7	0.0201	-0.0226	1.30	88.9	12.9	0.0426	5.2	0.76	.23
1TY-1227-14A	93	200	53.0	0.0822	7.43	1.67	139	20.1	b	b	0.78	69.6	10.1	b	4.7	0.68	.12
1TY-1227-1B	93	200	52.4	0.0813	7.34	1.65	141	20.4	b	b	0.78	70.3	10.2	b	4.9	0.71	.12
1TY-1227-8B	93	200	52.6	0.0816	7.38	1.66	140	20.3	b	b	0.75	70.3	10.2	b	4.9	0.71	.11
1TY-1227-3A	135	275	52.5	0.0813	6.89	1.55	130	18.9	b	b	0.60	64.8	9.4	b	5.0	0.73	.06
1TY-1227-21A	135	275	52.8	0.0818	6.94	1.56	130	18.9	b	b	1.00	65.5	9.5	b	5.0	0.73	.09
1TY-1227-14B	135	275	53.0	0.0822	6.85	1.54	123	17.8	b	b	0.83	61.4	8.9	b	5.0	0.72	.06

a - Strain exceeded recording equipment range before exceeding strain range of gage

b - Strain exceeded strain range of gage (= 0.0300)

TABLE 24b

IN-PLANE SHEAR (±45° TENSION) TEST RESULTS FOR WET, T300/5208 MATERIAL

Specimen ID	Temperature °C	Temperature °F	Area mm^2	Area $in.^2$	P_{ult}, kN	P_{ult}, kip	σ_{ult}, MPa	σ_{ult}, ksi	$\epsilon_{long_{max}}$	$\epsilon_{lat_{max}}$	ν	τ_{max} MPa	τ_{max} ksi	δ_{max}	G_{12} GPA	G_{12} psi x 10^6	G'_{12} psi x 10^6
1TY-1227-11A	-54	-65	55.1	0.0824	10.4	2.34	196	28.4	0.0128	-0.0102	0.92	97.9	14.2	0.0225	5.9	0.85	.36
1TY-1227-26A	-54	-65	52.3	0.0811	10.4	2.33	199	28.8	0.0115	-0.0097	0.75	95.8	13.9	0.0218	6.4	0.93	.30
1TY-1227-6B	-54	-65	52.9	0.0820	10.8	2.43	205	29.7	0.0112	-0.0092	0.75	102.0	14.8	0.0204	6.1	0.89	.40
1TY-1227-2B	22	72	52.5	0.0813	8.63	1.94	165	23.9	0.0273	-0.0242	0.79	82.0	11.9	0.0444	5.4	0.78	.23
1TY-1227-4B	22	72	52.6	0.0815	8.18	1.84	156	22.6	0.0231	-0.0224	0.73	77.9	11.3	0.0452	4.9	0.71	.18
1TY-1227-12B	22	72	52.8	0.0818	8.59	1.93	163	23.6	0.0259	-0.0242	0.76	81.4	11.8	0.0501	4.8	0.69	.19
1TY-1227-20B	93	200	52.9	0.0820	7.38	1.66	140	20.2	a	a	0.90	69.7	10.1	a	3.7	0.54	.08
1TY-1227-23B	93	200	52.5	0.0813	7.38	1.66	141	20.4	a	a	0.86	70.3	10.2	a	4.8	0.70	.08
1TY-1227-25B	93	200	52.7	0.0817	7.25	1.63	138	20.0	a	a	0.90	68.9	10.0	a	4.2	0.61	.05
1TY-1227-13A	135	275	52.9	0.0820	6.63	1.49	138	18.1	a	a	1.60	62.1	9.0	a	4.5	0.66	.07
1TY-1227-9B	135	275	52.7	0.0817	6.89	1.55	131	19.0	a	a	1.00	65.5	9.5	a	4.2	0.61	.06
1TY-1227-19B	135	275	53.4	0.0827	6.14	1.38	115	16.7	a	a	1.00	57.9	8.4	a	4.6	0.66	.05

a - Strain exceeded strain range of gage (= 0.0300)

TABLE 25

IN-PLANE SHEAR (±45° TENSION) TEST RESULTS FOR DRY AND WET AS/3501-5A MATERIAL

Specimen ID	Temperature °C	Temperature °F	Area mm^2	Area $in.^2$	P_{ult}, kN	P_{ult}, kip	σ_{ult}, MPa	σ_{ult}, ksi	ν	τ_{max} MPa	τ_{max} ksi	δ_{max}	GPa	G_{12} psi x 10^6	G'_{12} psi x 10^6
1TJ-1281-1A	22D	72D	55.5	0.0860	9.30	2.09	168	24.3	1.33	83.4	12.1	b	5.3	0.77	.22
1TJ-1281-11A	22D	72D	54.4	0.0843	9.43	2.12	170	24.7	2.12	83.4	12.1	a	4.6	0.67	.22
1TJ-1281-13A	22D	72D	54.2	0.0840	9.70	2.18	169	24.5	1.50	84.1	12.2	b	5.2	0.75	.22
1TJ-1281-6A	135W	275W	55.3	0.0857	6.94	1.56	125	18.2	1.00	62.7	9.1	a	2.6	0.38	.05
1TJ-1281-9A	135W	275W	53.5	0.0830	6.63	1.49	124	18.0	1.75	62.1	9.0	a	3.7	0.54	.05
1TJ-1281-10B	135W	275W	53.0	0.0822	6.58	1.48	124	18.0	0.88	62.1	9.0	a	3.7	0.53	.08

NOTE:

. Strain exceeded strain range of gage (= 0.0300)

· Surface breakup of specimen resulted in incorrect strain measurements before strain range limit of gage was reached.

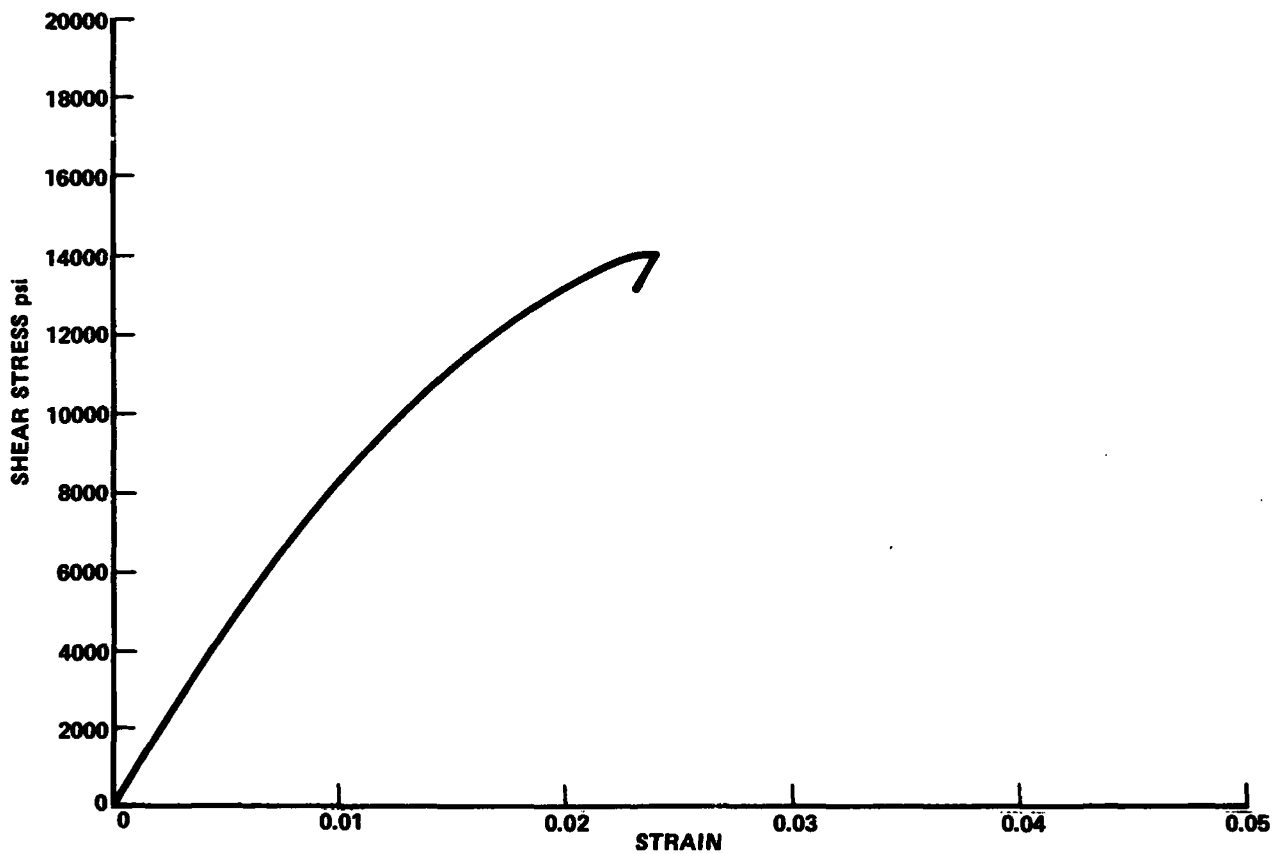


Figure 65. - In-plane shear stress-shear strain curve from tension test of ±45° T300/5208 specimen 1TY1227-18B, tested at -54°C (65°F) dry.

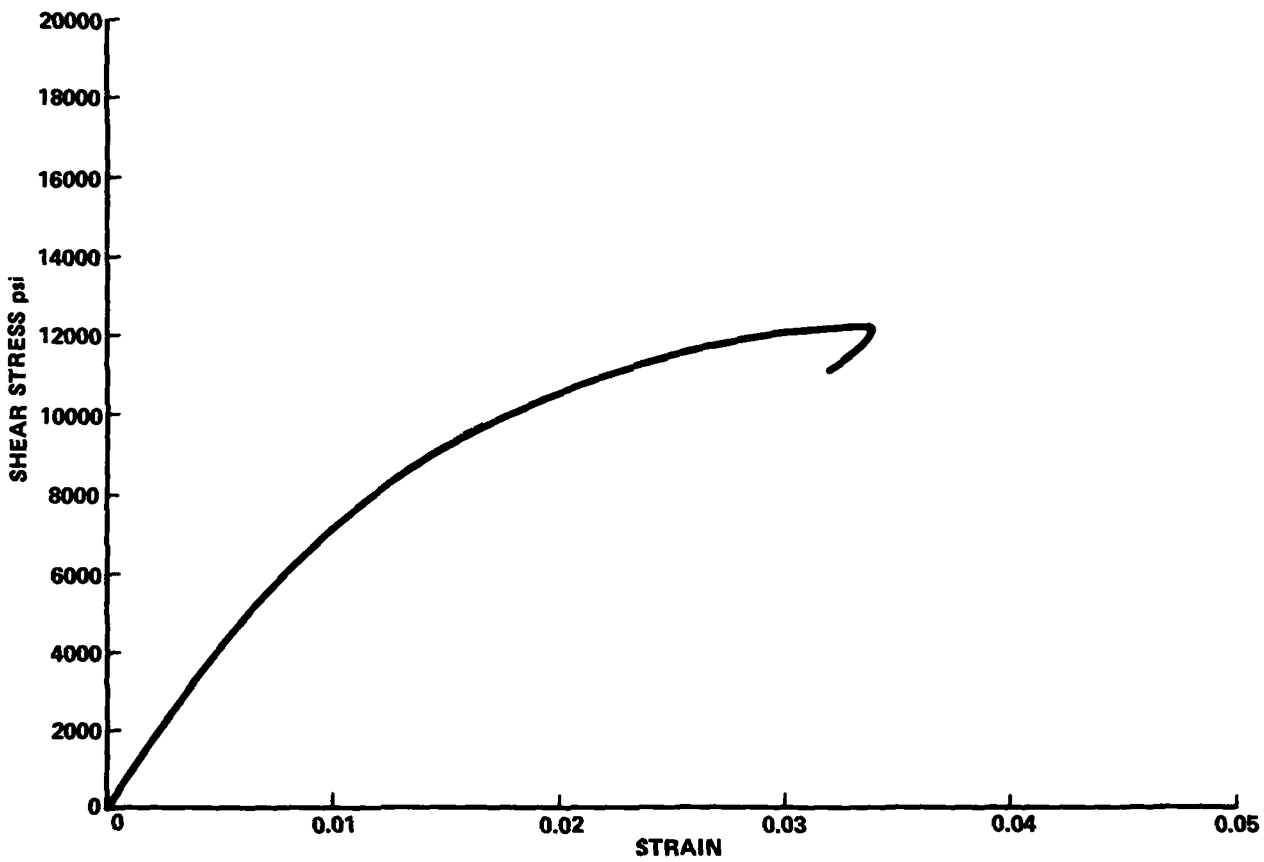


Figure 66. - In-plane shear stress-shear strain curve from tension test of ±45° T300/5208 specimen 1TY1227-4A, tested at 22°C (72°F) dry.

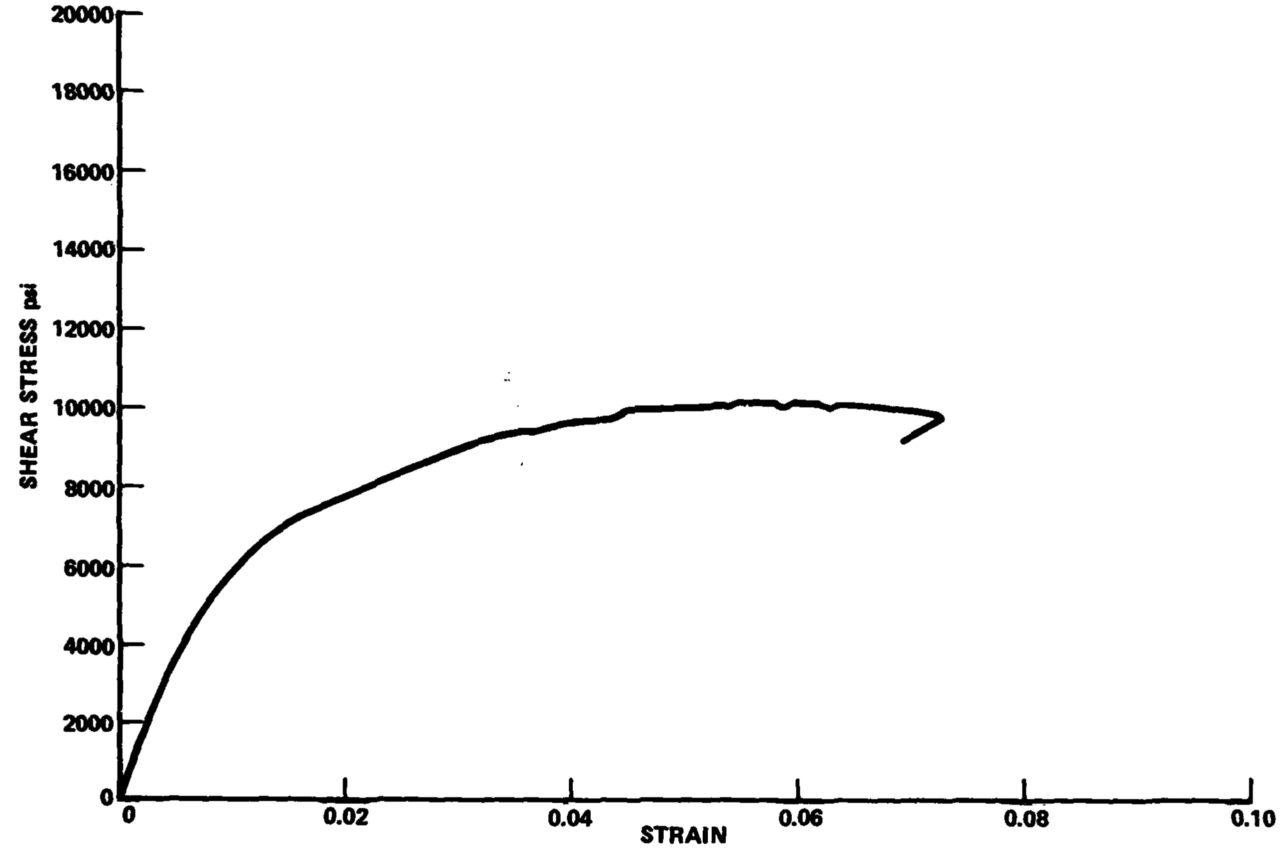


Figure 67. - In-plane shear stress-shear strain curve from tension test of ±45° T300/5208 specimen 1TY1227-3B, tested at 93° (200°F) dry.

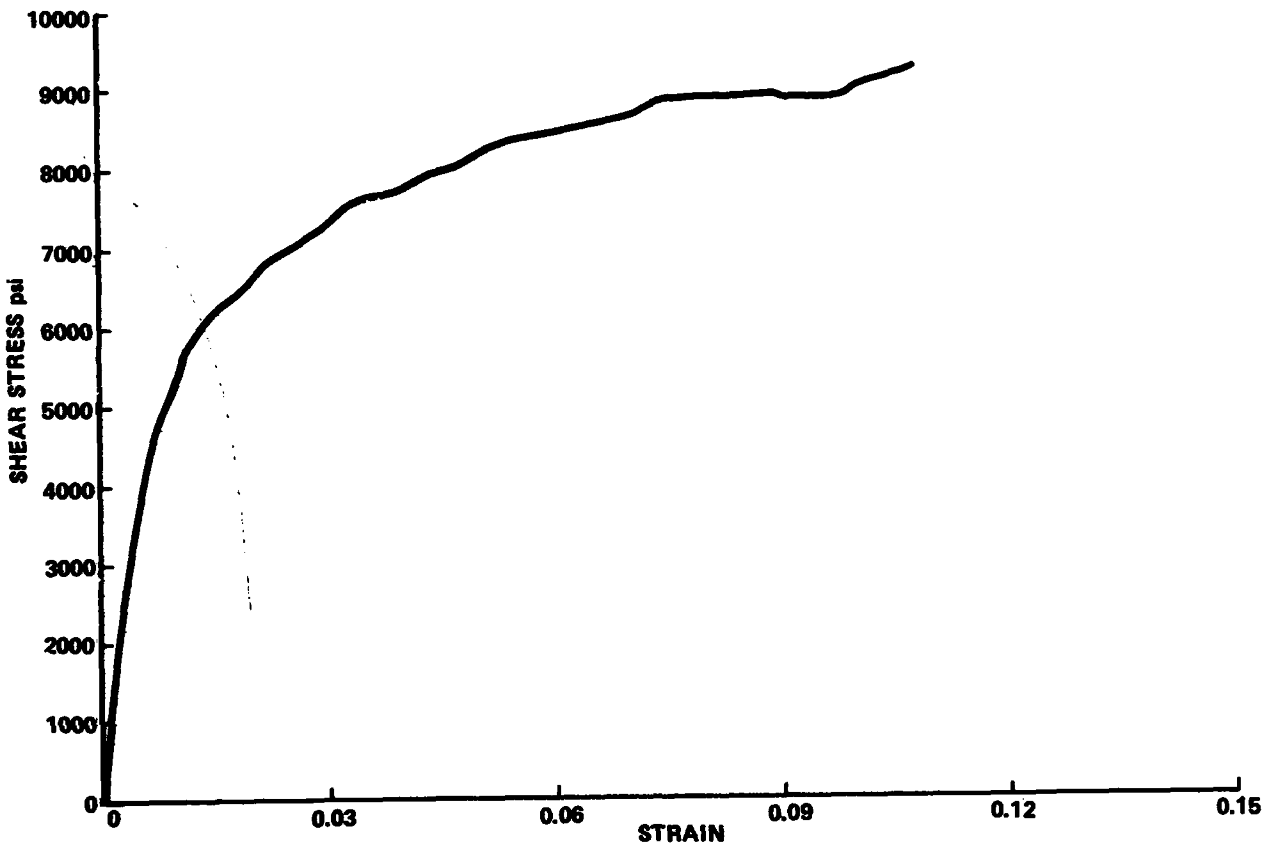


Figure 68. - In-plane shear stress-shear strain curve from tension test of ±45° T300/5208 specimen 1TY1227-21A, tested at 135° (275°F) dry.

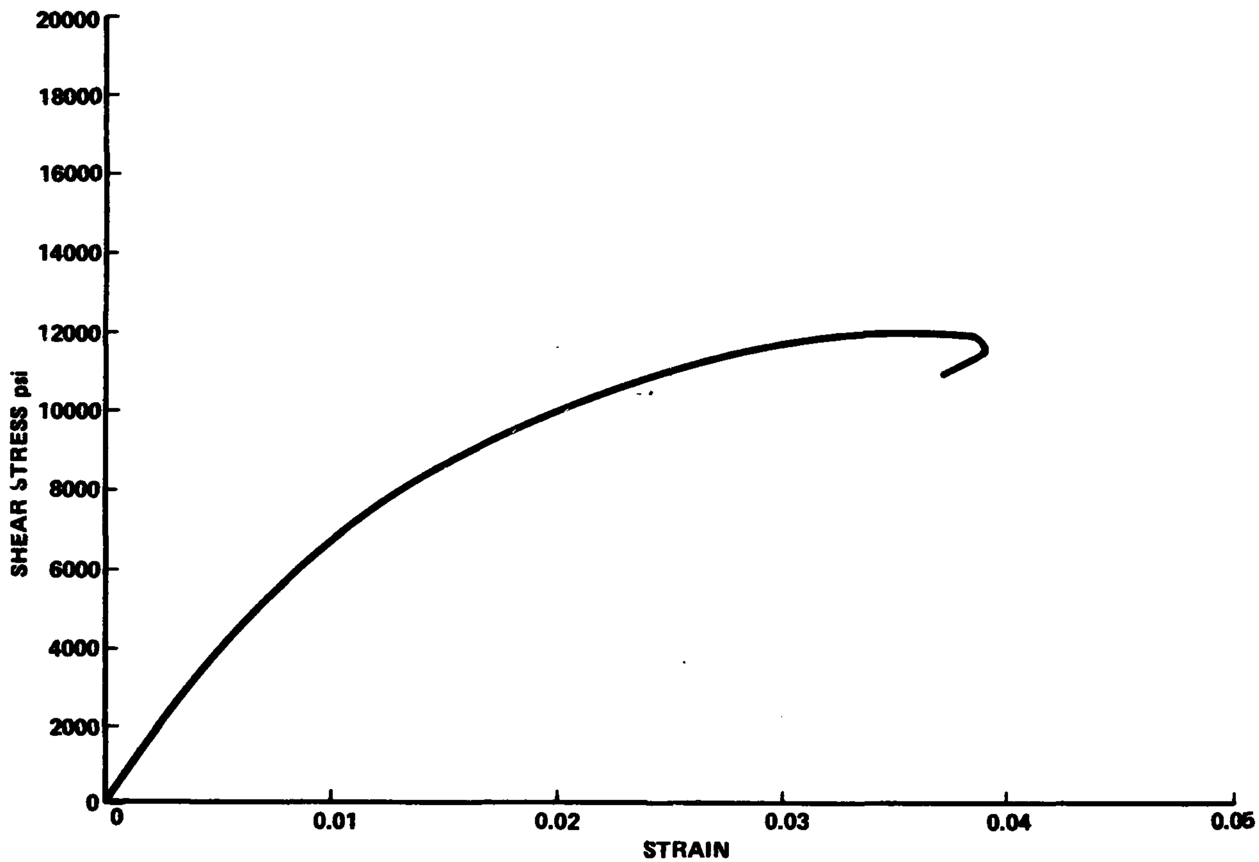


Figure 69. - In-plane shear stress-shear strain curve from tension test of ±45° AS/3501-5A specimen 1TJ1281-1A, tested at 22°C (72°F) dry.

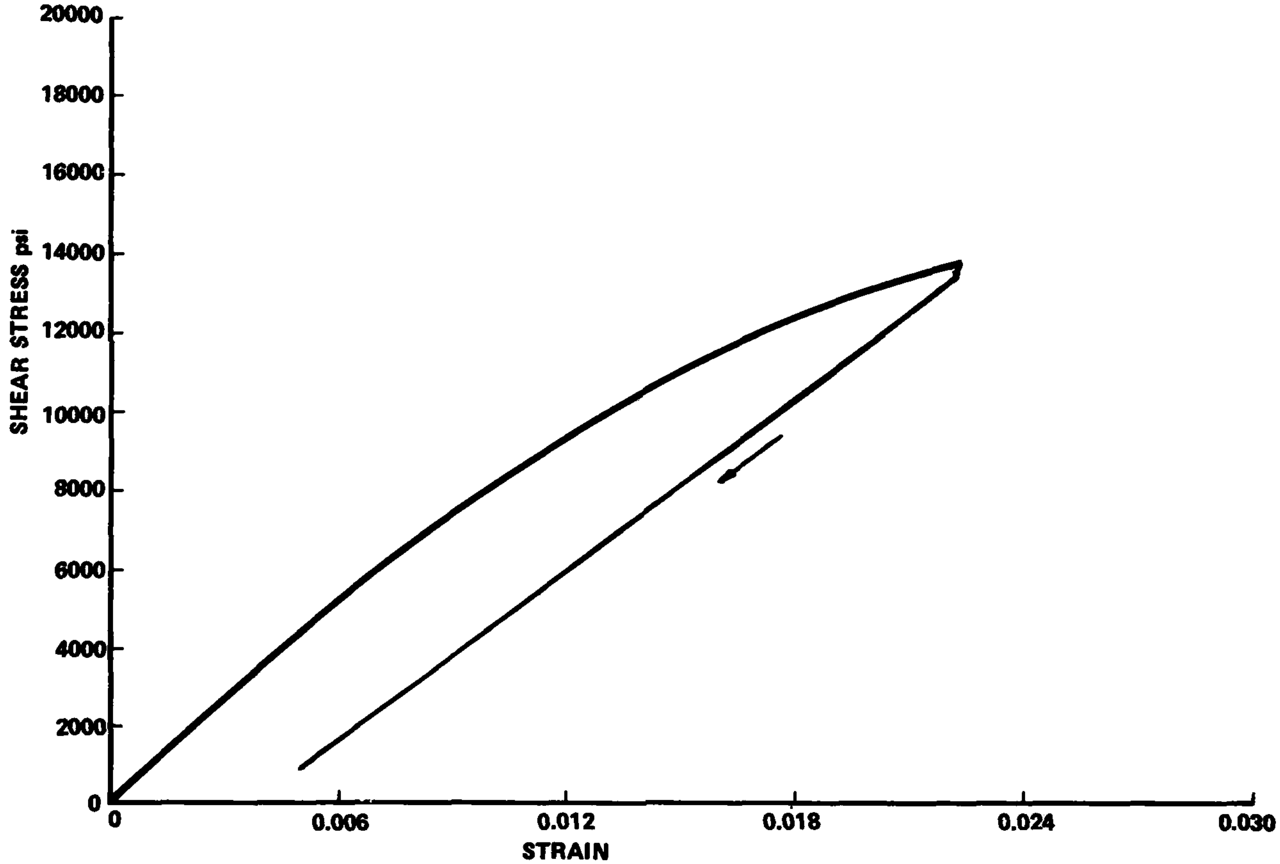


Figure 70. - In-plane shear stress-shear strain curve from tension test of ±45° T300/5208 specimen 1TY1227-11A, tested at -54°C (-65°F) wet.

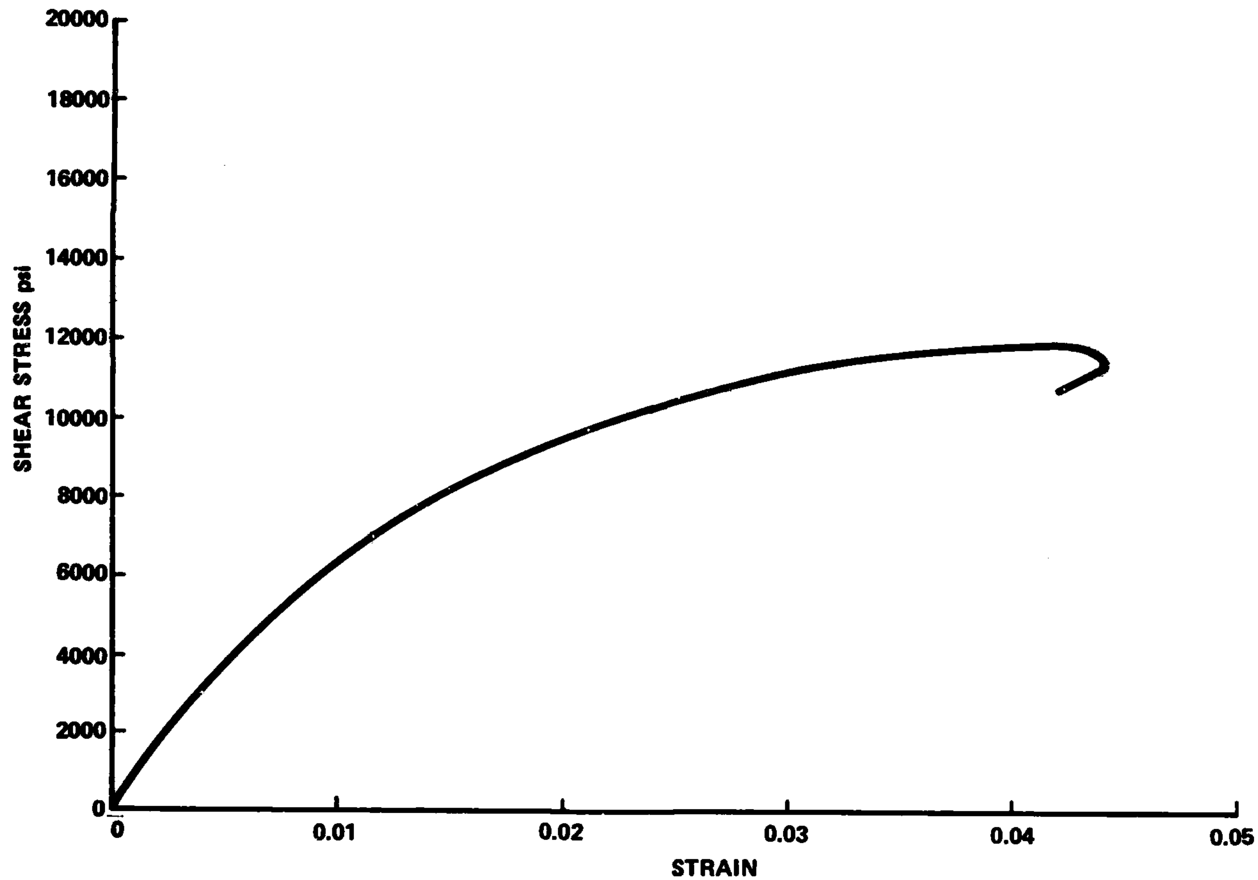


Figure 71. - In-plane shear stress-shear strain curve from tension test of ±45° T300/5208 specimen 1TY1227-2B, tested at 22°C (72°F) wet.

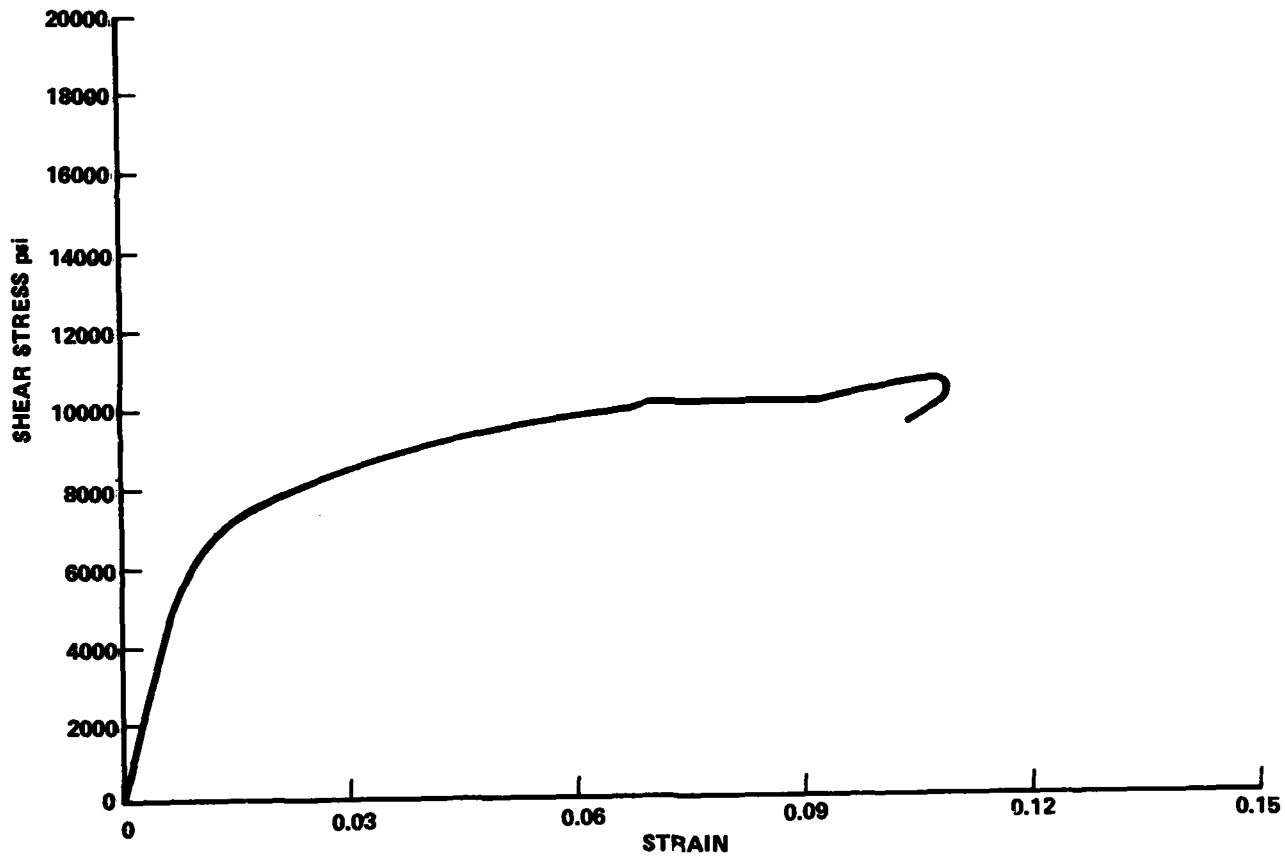


Figure 72. - In-plane shear stress-shear strain curve from tension test of ±45° T300/5208 specimen 1TY1227-23B, tested at 93°C (200°F) wet.

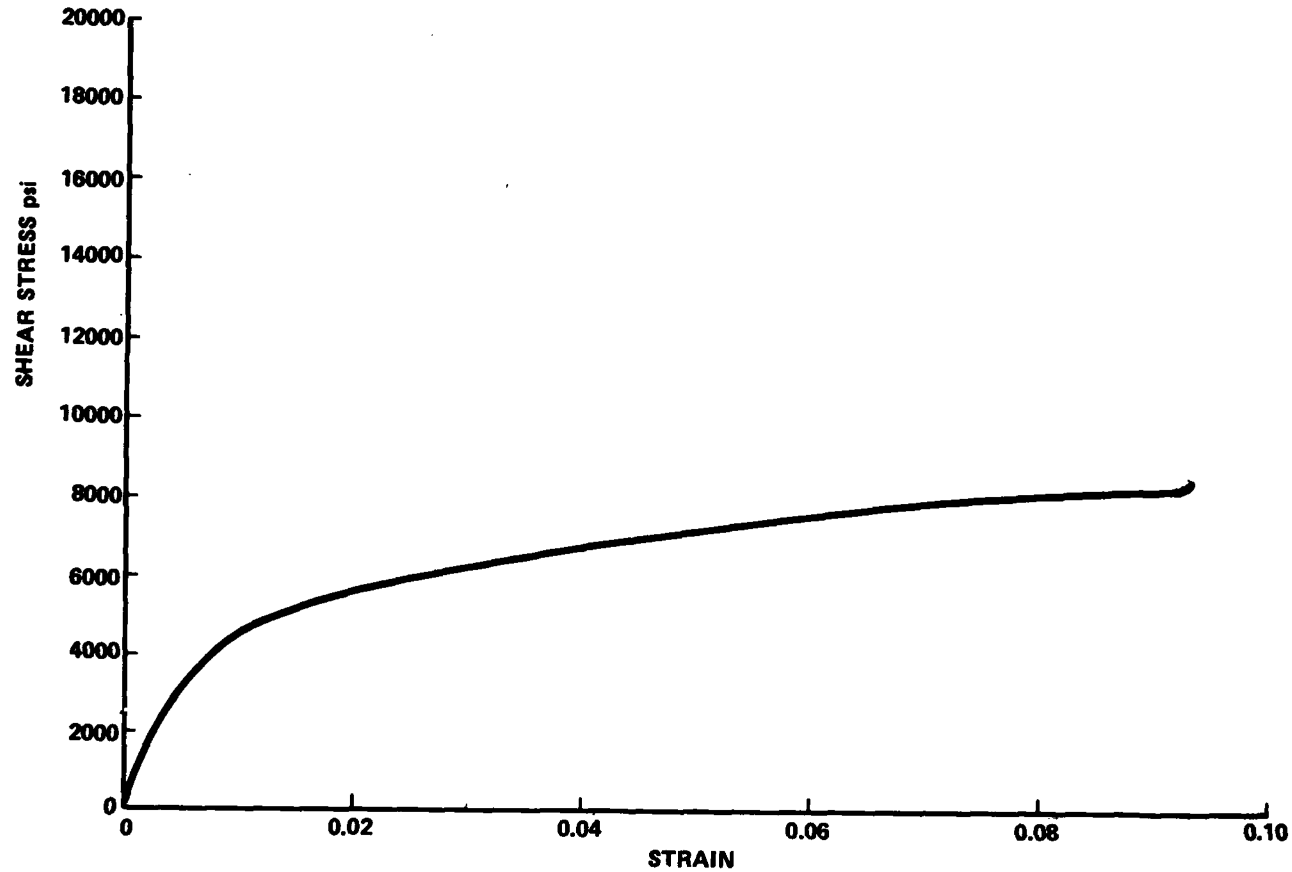


Figure 73. - In-plane shear stress-shear strain curve from tension test of ±45° T300/5208 specimen 1TY1227-13A, tested at 135°C (275°F) wet.

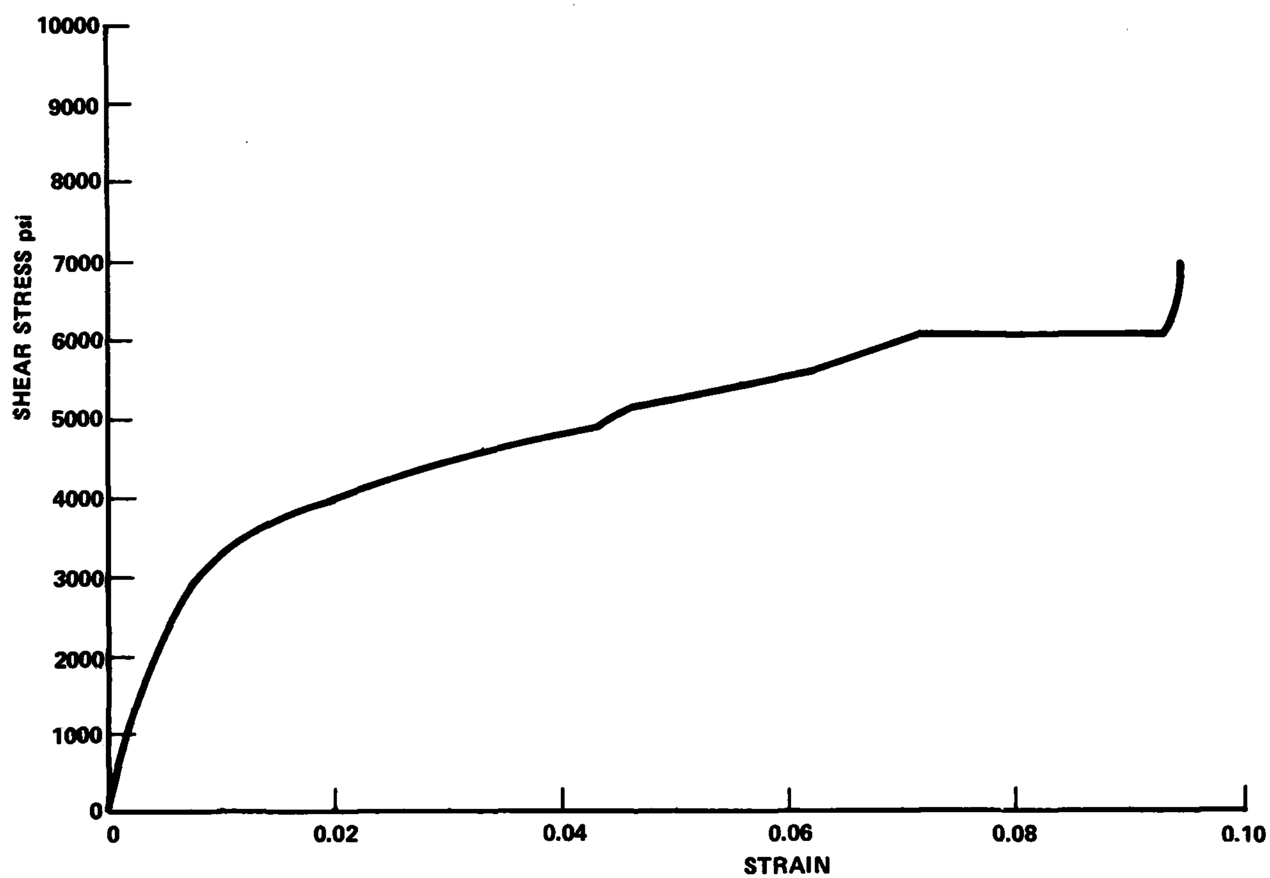


Figure 74. - In-plane shear stress-shear strain curve from tension test of ±45° AS/3501-5A specimen 1TJ1291-9A, tested at 135°C (275°F) wet.

4.6 Fully Supported Compression Tests

4.6.1 Laminates L1 and L2 - T300/5208

The fully supported compression test data obtained at four temperatures for laminates L1 and L2 both longitudinal and transverse, "dry" (conditioned at 22°C (72°F) and 40% RH) and "wet" (conditioned at 82°C (135°F) and 90% RH) are presented in Tables 26 through 33. Compression stress-strain curves for all of these laminates were non-linear, with a smooth continuous curve. Secant moduli were evaluated at maximum stress for all the laminates, and at 17 ksi for L2, transverse (L2T), 35 ksi for L1, longitudinal (L1L) and L1, transverse (L1T) and 70 ksi for L2, longitudinal (L2L). Use of the secant modulus allows an unbiased comparison of the modulus at various temperatures. There is no significant change in the modulus for any of the four laminate types over the temperature range of -54°C (-65°F) to 135°C (275°F).

Strength and failure strain generally appear to trend towards decreasing values with increasing temperature, although the differences, especially from 22°C (72°F) to 135°C (275°F), are small and the data may fall into one scatter band for each laminate type. The failure appearances of the 22°C (72°F), 93°C (200°F) and 135°C (275°F) specimens are also similar with the possible exception of L2L laminates which exhibit a slight amount of plastic flow in the matrix. Specimens tested at -54°C (-65°F) displayed slightly more cracking and crushing than those tested in lab air or at elevated temperatures. The L1L and L1T specimens separated into two pieces at -54°C (-65°F), but usually remained intact in tests at the other three temperatures. Typical failed specimens are shown in Figures 75 through 82.

Considerable scatter in the data is evident, particularly for the L2L laminate, which is not totally unexpected in a laminate containing such a high percentage of 0 degree plies. Most failures occurred in the gage section at least one inch away from the tabs. However, these failures often coincided with the holes cut in the support platens to accommodate the extensometer points. These cutouts often leave an imprint on the failed specimen such as is evident on the L1L coupon in Figure 81. Most likely, after failure the fractured pieces are forced out against the holes. Nevertheless, to be certain

TABLE 26a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY LAMINATE L1, LONGITUDINAL - T300/5208

Specimen ID	Temperature °F	Average Area, in.^{2}	Ultimate Load, P_{ult}, kip	Ultimate Stress, σ_{ult}, ksi	Ultimate Strain, ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure, E_{sf}, psi x 10^6	Secant Modulus, at 35 ksi E_{s35}, psi x 10^6	Failure[a] Location
1TY1224-12B	-65	0.0831	7.7	93.1	0.0153	6.1	7.1	G
1TY1224-22B	-65	0.0835	7.2	86.5	0.0144	6.0	7.2	G
1TY1226-22A	-65	0.0804	5.8	72.4	0.0112	6.5	6.9	G
2TY1218-11B	72	0.0806	6.3	78.1	0.0128	6.1	7.0	G
2TY1218-27A	72	0.0818	5.0	61.5	0.0096	6.4	7.0	G
1TY1226-31B	72	0.0818	5.9	72.4	0.0111	6.5	7.1	G
2TY1218-15A	200	0.0803	5.6	69.4	0.0111	6.2	7.1	G
2TY1218-18A	200	0.0803	4.8	59.4	0.0090	6.6	7.2	G
1TY1224-9A	200	0.0829	4.4	53.4	0.0081	6.6	6.9	½ W
2TY1218-1B	275	0.0796	5.0	62.7	0.0103	6.1	7.1	G
1TY1224-11B	275	0.0828	4.7	57.1	0.0091	6.3	6.7	W
1TY1224-30A	275	0.0828	5.8	70.6	0.0108	6.1	6.7	G

a G - gage section one inch from tabs. W - between ½ and 1 specimen width (1 inch) away from tab.
½ W - between tab end and ½ width from tab end.

TABLE 26b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY LAMINATE 11, LONGITUDINAL - T300/5208

Specimen ID	Temperature °C	Average Area mm^2	Ultimate Load, P_{ult}, kN	Ultimate Stress, σ_{ult}, MPa	Ultimate Strain, ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 241 MPa $E_{\epsilon 241}$, GPa	Failure Location[a]
1TY1224-12B	-54	53.6	34.2	641.9	0.0153	42.1	49.0	G
1TY1224-22B	-54	53.9	32.0	596.4	0.0144	41.4	49.6	G
1TY1226-22A	-54	51.9	25.8	499.2	0.0112	44.8	47.6	G
2TY1218-11B	22	52.0	28.0	538.5	0.0128	42.1	48.3	G
2TY1218-27A	22	52.8	22.2	424.0	0.0096	44.1	48.3	G
1TY1226-31B	22	52.8	26.2	459.2	0.0111	44.8	49.0	G
2TY1218-15A	93	51.8	24.9	478.5	0.0111	42.8	49.0	G
2TY1218-18A	93	51.8	21.4	409.6	0.0090	45.5	49.6	G
1TY1224-9A	93	53.5	19.6	368.2	0.0081	45.5	47.6	½ W
2TY1218-1B	135	51.4	22.2	432.3	0.0103	42.1	49.0	G
1TY1224-11B	135	53.4	20.9	393.7	0.0091	43.4	46.2	W
1TY1224-30A	135	53.4	25.8	486.8	0.0108	42.1	46.2	G

a - G - gage section one inch from tabs. W - between ½ and 1 specimen width (1 inch) away from tab.
½ W - between tab end and ½ width from tab end

TABLE 27a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR WET LAMINATE L1, LONGITUDINAL - T300/5208

Specimen ID	Temperature °F	Average Area, in.^{2}	Ultimate Load, P_{ult}, kip	Ultimate Stress, σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Secant Modulus, at 35 ksi, E_{s35}, psi x 10^6	Failure[a] Location
1TY1224-6A	-65	0.0826	6.8	82.8	0.0133	6.2	7.0	G
1TY1224-7B	-65	0.0826	6.7	81.6	0.0145	5.6	6.9	G
1TY1224-16B	-65	0.0838	6.8	8C.8	0.0131	6.2	7.1	G
2TY1218-28A	72	0.0812	5.7	70.5	0.0108	6.6	7.3	G
2TY1218-35B	72	0.0814	5.7	70.7	0.0108	6.6	7.3	G
1TY1226-16A	72	0.0813	6.5	79.9	0.0120	6.6	7.3	G
1TY1224-37B	200	0.0829	4.4	53.6	0.0074	6.8	7.1	G
1TY1226-15B	200	0.0811	5.2	64.6	0.0098	6.6	6.9	½ W
1TY1226-24B	200	0.0814	4.4	54.5	0.0101	5.4	6.7	G
2TY1218-10P	275	0.0815	5.1	63.0	0.0094	6.7	7.0	G
2TY1218-26B	275	0.0812	5.1	62.5	0.0107	5.8	7.0	G
1T11226-31A	275	0.0818	5.3	64.5	0.0094	6.8	7.2	G
2TY1218-41B	275	0.0817	4.8	57.0	0.0086	6.7	7.3	G
1TY1224-4A	275	0.0828	4.6	56.0	-	-	-	G
1TY1224-19B	275	0.0836	5.6	67.2	0.0104	6.5	7.1	G
1TY1226-12A	275	0.0814	4.6	56.4	0.0080	7.1	7.1	G
1TY1226-26A	275	0.0813	4.6	56.6	0.0082	6.9	7.1	1/2 W
1TY1226-9B	275	0.0816	4.7	57.4	0.0092	6.2	7.9	G

a - G - gage section one inch from tabs. 1/2 W - between tab end and 1/2 width from tab end.

TABLE 27b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR WET LAMINATE L1, LONGITUDINAL - T300/5208

Specimen ID	Temperature °C	Average Area mm^2	Ultimate Load P_{ult}, kN	Ultimate Stress, σ_{ult}, Mpa	Ultimate Strain, ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 241 MPa E_{s241}, GPa	Failure Location[a]
1TY1224-6A	-54	53.3	30.2	570.9	0.0133	42.7	48.3	G
1TY1224-7B	-54	53.3	29.8	562.6	0.0145	38.6	47.6	G
1TY1224-16B	-54	54.1	30.2	570.1	0.0131	42.7	49.0	G
2TY1218-28A	22	52.4	25.4	486.1	0.0108	45.5	50.3	G
2TY1218-35B	22	52.5	25.4	487.5	0.0108	45.5	50.3	G
1TY1226-16A	22	52.5	28.9	550.9	0.0120	45.5	50.3	G
1TY1224-37B	93	53.5	19.6	369.6	0.0074	46.9	49.0	G
1TY1226-15B	93	52.3	23.1	445.4	0.0098	45.5	47.6	1/2W
1TY1226-24B	93	52.5	19.6	375.8	0.0101	37.2	46.2	G
2TY1218-10B	135	52.6	22.7	434.4	0.0094	46.2	48.3	G
2TY1218-26B	135	52.4	22.7	430.9	0.0107	40.0	48.3	G
1TY1226-31A	135	52.8	23.6	444.7	0.0094	46.9	49.6	G
2TY-1218-41B	135	52.7	21.2	393	0.0086	46	50	G
1TY-1224-4A	135	53.4	20.6	386	--	--	--	G
1TY-1224-19B	135	53.9	25.0	463	0.0104	45	49	G
1TY-1226-12A	135	52.5	20.4	389	0.0080	49	49	G
1TY-1226-26A	135	52.5	20.5	390	0.0082	48	49	1/2W
1TY-1226-9B	135	52.6	20.9	396	0.0092	43	54	G

a - G = gage section one inch from tabs.

1/2 W = between tab end and 1/2 width from tab end.

TABLE 28a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY LAMINATE L1, TRANSVERSE - T300/5208

Specimen ID	Temperature °F	Average Area, in.^{2}	Ultimate Load, P_{ult}, kip	Ultimate Stress, σ_{ult}, ksi	Ultimate Strain, ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure, E_{sf}, psi x 10^6	Secant Modulus, at 35 ksi, E_{s35}, psi x 10^6	Failure Location[a]
2TY1218-11C	-65	0.0810	6.2	76.5	0.0114	6.7	7.3	G
2TY1218-15F	-65	0.0814	6.5	79.4	0.0128	6.2	6.9	G
1TY1224-18E	-65	0.0828	7.2	87.4	0.0134	6.4	7.2	G
1TY1226-5C	72	0.0814	4.5	55.3	0.0083	6.7	7.3	G, dlm
1TY1226-17C	72	0.0808	4.9	60.2	0.0090	6.7	7.3	G
1TY1226-6D	72	0.0822	4.9	59.1	0.0090	6.6	7.0	G
1TY1224-4D	200	0.0828	4.9	59.6	0.0094	6.4	6.9	G
1TY1224-13F	300	0.0835	5.4	65.2	0.0099	6.6	7.1	½ W
1TY1224-18F	200	0.0827	4.8	58.2	0.0093	6.3	6.3	W
2TY1218-5D	275	0.0808	4.7	58.2	0.0090	6.4	7.2	G
2TY1218-9E	275	0.0822	4.6	55.4	0.0089	6.2	6.9	G
1TY1226-3F	275	0.0814	4.5	55.4	0.0085	6.5	7.1	G

a - G - gage section one inch from tabs. W-between ½ and 1 specimen width (1 inch) away from tab.
½ W - between tab end and ½ width from tab end. dlm - outer plies delaminated only.

TABLE 28b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY LAMINATE L1,TRANSVERSE - T300/5208

Specimen ID	Temperature ^{o}C	Average Area, mm^2	Ultimate Load, P_{ult}, kN	Ultimate Stress, σ_{ult}, MPa	Ultimate Strain, ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 241 MPa E_{s241}, GPa	Failure Location [a]
2TY1218-11C	-54	52.3	27.6	527.4	0.0114	46.2	50.3	G
2TY1218-15F	-54	52.5	28.9	547.4	0.0128	42.8	47.6	G
1TY1224-18E	-54	53.4	32.0	602.6	0.0134	44.1	49.6	G
1TY1226-5C	22	52.5	20.0	381.3	0.0083	46.2	50.3	G, dlm
1TY1226-17C	22	52.1	21.8	415.1	0.0090	46.2	50.3	G
1TY1226-6D	22	53.0	21.8	407.5	0.0090	45.5	48.3	G
1TY1224-4D	93	53.4	21.8	410.9	0.0094	44.1	47.6	G
1TY1224-13F	93	53.9	24.0	449.5	0.0099	45.5	49.0	½ W
1TY1224-18F	93	53.4	21.4	401.3	0.0093	43.4	43.4	W
2TY1218-5D	135	52.1	20.9	401.3	0.0090	44.1	49.6	G
2TY1218-9E	135	53.0	20.5	382.0	0.0089	42.8	47.6	G
1TY1226-3F	135	52.5	20.0	382.0	0.0085	44.8	49.0	G

a - G - gage section one inch from tabs. W - between ½ and 1 specimen width (1 inch) away from tab.
½ W - between tab end and ½ width from tab end. dlm - outer plies delaminated only

TABLE 29a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR WET LAMINATE L1, TRANSVERSE - T300/5208

Specimen ID	Temperature °F	Average Area, in.^{2}	Ultimate Load, P_{ult}, kip	Ultimate Stress, σ_{ult}, ksi	Ultimate Strain, ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure, E_{sf}, psi x 10^6	Secant Modulus, at 35 ksi, E_{s35}, psi x 10^6	Failure Location[a]
2TY1218-3C	-65	0.0807	5.7	70.9	0.0101	7.0	7.7	G
2TY1218-13F	-65	0.0820	6.2	76.1	0.0120	6.3	7.1	G
1TY1226-7C	-65	0.0821	5.3	65.0	0.0101	6.4	7.0	G
2TY1218-18D	72	0.0816	5.1	62.4	0.0096	6.5	7.2	G
2TY1218-9F	72	0.0818	5.0	60.8	0.0091	6.6	7.3	G
1TY1224-6E	72	0.0830	5.7	69.1	0.0107	6.5	7.3	G
2TY1218-14C	200	0.0806	4.3	53.8	0.0086	6.2	7.2	G
1TY1224-6C	200	0.0829	4.2	50.9	0.0082	6.2	6.7	G
1TY1224-8C	200	0.0820	4.1	50.2	0.0080	6.2	6.5	G
2TY1218-1D	275	0.0784	4.0	49.6	0.0082	6.0	6.8	G
2TY1218-6E	275	0.0824	4.9	59.2	0.0096	6.1	7.0	G
1TY1226-14C	275	0.0808	4.2	51.5	0.0085	6.0	6.8	G
2TY1218-2D	275	0.0816	4.1	50.1	-	-	-	G
2TY1218-2E	275	0.0818	4.0	49.1	0.0073	6.7	7.3	G
1TY1224-12C	275	0.0828	4.5	54.8	0.0117	4.7	7.3	G
1TY1226-4D	275	0.0816	4.1	50.2	0.0078	6.4	6.9	G
1TY1226-19D	275	0.0818	4.4	54.1	0.0085	6.4	6.9	G
1TY1226-5F	275	0.0815	3.9	48.3	0.0080	6.1	6.6	G

a = G - gage section one inch from tabs.

TABLE 29b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR WET LAMINATE L1, TRANSVERSE - T300/5208

Specimen ID	Temperature °C	Average Area mm^2	Ultimate Load, P_{ult}, kN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain, ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 241 MPa E_{s241}, GPa	Failure Location[a]
2TY1218-3C	-54	52.1	25.4	488.8	0.0101	48.3	53.1	G
2TY1218-13F	-54	52.9	27.6	524.7	0.0120	43.4	48.9	G
1TY1226-7C	-54	53.0	23.6	448.2	0.0101	44.1	48.3	G
2TY1218-18D	22	52.6	22.7	430.2	0.0096	44.8	49.6	G
2TY1218-9F	22	52.8	22.2	419.2	0.0091	45.5	50.3	G
1TY1224-6E	22	53.5	25.4	476.4	0.0107	44.8	50.3	G
2TY1218-14C	93	52.0	19.1	370.9	0.0086	42.7	49.6	G
1TY1224-6C	93	53.5	18.7	350.9	0.0082	42.7	46.2	G
1TY1224-8C	93	52.9	18.2	346.1	0.0080	42.7	44.8	G
2TY1218-1D	135	50.6	17.8	342.0	0.0082	41.4	46.9	G
2TY1218-6E	135	53.2	21.8	408.2	0.0096	42.1	48.3	G
1TY1226-14C	135	52.1	18.7	350.1	0.0085	41.4	46.9	G
2TY-1218-2D	135	52.6	18.2	345	--	--	--	G
2TY-1218-2E	135	52.8	17.9	339	0.0073	46	50	G
1TY-1224-12C	135	53.4	20.2	378	0.0117	32	50	G
1TY-1226-4D	135	52.6	18.2	346	0.0078	44	48	G
1TY-1226-19D	135	52.8	19.7	373	0.0085	44	48	G
1TY-1226-5F	135	52.6	17.5	333	0.0080	42	46	G

a - G = gage section one inch from tabs.

TABLE 30a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY LAMINATE L2, LONGITUDINAL - T300/5208

Specimen ID	Temperature °F	Average Area, in.^{2}	Ultimate Load, P_{ult}, kip	Ultimate Stress, σ_{ult}, ksi	Ultimate Strain, ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure, E_{sf} psi x 10^6	Secant Modulus, at 70 ksi E_{s70}, psi x 10^6	Failure Location[a]
2TY1225-1A	-65	0.1135	14.4	126.8	-[b]	-[b]	-[b]	G
2TY1226-16B	-65	0.1214	17.4	143.3	0.0121	11.8	13.7	G
2TY1226-17B	-65	0.1218	19.8	162.9	0.0146	11.2	13.3	G
2TY1225-7A	72	0.1210	13.9	115.2	-[b]	-[b]	13.4	G
2TY1225-37A	72	0.1205	13.8	114.8	0.0094	12.3	12.4	W, dlm
2TY1226-6B	72	0.1199	19.4	161.9	0.0143	11.3	13.2	G
1TY1225-4A	200	0.1207	10.1	83.5	0.0064	12.9	13.1	W
2TY1225-10B	200	0.1210	16.4	135.5	0.0130	10.4	13.3	G
2TY1226-9B	200	0.1212	16.6	136.8	0.0114	12.0	13.0	G
1TY1225-13A	275	0.1211	13.9	114.6	0.0099	11.6	12.7	G
1TY1225-35B	275	0.1217	13.2	108.6	0.0092	11.8	12.7	G
2TY1225-22A	275	0.1206	11.7	97.0	0.0079	12.2	11.8	G
2TY1225-33B	275	0.1220	17.9	146.4	0.0127	11.5	14.1	G
2TY1226-23B	275	0.1205	12.8	106.3	0.0090	11.8	12.8	G
2TY1226-36A	275	0.1210	12.7	104.6	0.0083	12.6	13.2	G

a - G gage section one inch from tabs. W - between 1/2 and 1 specimen width (1 inch) away from tab. $\frac{1}{2}$ W - between tab end and $\frac{1}{2}$ width from tab end. dlm - outer plies delaminated only.

b - Numerous horizontal jumps in σ- ϵ curve accompanied by popping sounds; failure strain undefined.

TABLE 30b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY LAMINATE L2, LONGITUDINAL - T300/5208

Specimen ID	Temperature °C	Average Area, mm^2	Ultimate Load, P_{ult}, kN	Ultimate Stress, σ_{ult}, MPa	Ultimate Strain, ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 482 MPa E_{s482}, GPa	Failure Location [a]
2TY1225-1A	-54	73.2	64.0	874.2	- [b]	- [b]	- [b]	G
2TY1226-16B	-54	78.3	77.4	988.0	0.0121	81.4	94.4	G
2TY1226-17B	-54	78.6	88.1	724.6	0.0146	77.2	91.7	G
2TY1225-7A	22	78.1	61.8	794.3	- [b]	- [b]	92.4	G
2TY1225-37A	22	77.7	61.4	791.5	0.0094	84.8	85.5	W, dlm
2TY1226-6B	22	77.4	86.3	1116.3	0.0143	77.9	91.0	G
1TY1225-4A	93	77.9	44.9	575.7	0.0064	88.9	90.3	W
2TY1225-10B	93	78.1	73.0	934.2	0.0130	71.7	91.7	G
2TY1226-9B	93	78.2	73.8	943.2	0.0114	82.7	89.6	G
1TY1225-13A	135	78.1	61.8	790.1	0.0099	80.0	87.6	G
1TY1225-35B	135	78.5	58.7	748.8	0.0092	81.3	87.6	G
2TY1225-22A	135	77.8	52.0	668.8	0.0079	84.1	81.4	G
2TY1225-33B	135	78.7	79.6	1009.4	0.0127	79.3	97.2	G
2TY1226-23B	135	77.7	56.9	732.9	0.0090	81.3	88.2	G
2TY1226-36A	135	78.1	56.5	721.2	0.0083	86.9	91.0	G

a - G - gage section one inch from tabs. W - between ½ and 1 specimen width (1 inch) away from tab.
½ W - between tab end and ½ width from tab end. dlm - outer plies delaminated only

b - Numerous horizontal jumps in σ-ε curve accompanied by popping sounds; failure strain undefined.

TABLE 31a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR WET LAMINATE L1, LONGITUDINAL - T300/5208

Specimen ID	Temperature ^oF	Average Area, in.^{2}	Ultimate Load, P_{ult}, kip	Ultimate Stress, σ_{ult}, ksi	Ultimate Strain, ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure, E_{sf}, psi x 10^6	Secant Modulus, at 70 ksi, E_{s70}, psi x 10^6	Failure Location[a]
2TY1225-25B	-65	0.1208	17.2	142.2	0.0128	11.1	13.6	G
2TY1226-4A	-65	0.1214	14.5	119.7	0.0099	12.1	12.9	G
2TY1226-26B	-65	0.1221	17.6	144.9	0.0132	10.9	13.6	G
1TY1225-31A	72	0.1225	17.5	142.7	0.0129	11.1	12.7	G
2TY1225-23A	72	0.1222	16.2	132.8	0.0116	11.4	12.8	1/2 W
2TY1225-15B	72	0.1224	17.7	144.6	0.0126	11.5	12.8	G
1TY1225-29B	200	0.1224	14.6	119.6	0.0107	11.1	12.0	G
2TY1225-24A	200	0.1217	13.4	110.2	0.0159	-[b]	13.0	G
2TY1225-35A	200	0.1201	13.7	114.2	0.0136	-[b]	12.7	1/2 W
1TY1225-10B	275	0.1213	13.0	107.2	0.0083	12.9	12.5	1/2 W
2TY1225-27B	275	0.1224	15.8	129.4	0.0112	11.6	14.0	1/2 W
2TY1225-28B	275	0.1227	14.8	120.3	0.0095	12.6	12.8	G
1TY1225-36A	275	0.1212	12.3	101.2	0.0088	11.5	12.8	G
1TY1225-40A	275	0.1211	13.1	108.3	-	-	13.0	1/2 W
1TY1225-7B	275	0.1206	13.2	109.3	-	-	12.5	W
2TY1225-5B	275	0.1201	12.4	103.2	0.0084	12.3	13.0	G
2TY1226-7A	275	0.1205	13.3	110.0	-	-	13.3	1/2 W
2TY1226-10B	275	0.1210	11.3	93.7	0.0077	12.2	13.0	G

a - G - gage section one inch from tabs. 1/2 W - between tab end and 1/2 width from tab end.

b - Numerous horizontal jumps in the σ - ϵ curve accompanied by popping sounds; failure strain undefined.

TABLE 31b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR WET LAMINATE L2, LONGITUDINAL - T300/5208

Specimen ID	Temperature °C	Average Area mm^2	Ultimate Load, P_{ult}, kN	Ultimate Stress, σ_{ult}, MPa	Ultimate Strain, ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 482 MPa E_{s482}, GPa	Failure Location[a]
2TY1225-25B	-54	77.9	76.5	980.4	0.0128	76.5	93.8	G
2TY1226-4A	-54	78.3	64.5	825.3	0.0099	83.4	88.9	G
2TY1226-26B	-54	78.8	78.3	999.1	0.0132	75.2	93.8	G
1TY1225-31A	22	79.0	77.8	983.9	0.0129	76.5	87.6	G
2TY1225-23A	22	78.8	72.1	915.6	0.0116	78.6	88.3	½ W
2TY1225-15B	22	79.0	78.7	997.0	0.0126	79.3	88.3	G
1TY1225-29B	93	79.0	64.9	824.6	0.0107	76.5	82.7	G
2TY1225-24A	93	78.5	59.6	759.8	0.0159	-[b]	89.6	G
2TY1225-35A	93	77.5	60.9	787.4	0.0136	-[b]	87.6	½ W
1TY1225-10B	135	78.3	57.8	739.1	0.0083	88.9	86.2	½ W
2TY1225-27B	135	79.0	70.3	892.2	0.0112	80.0	96.5	½ W
2TY1225-28B	135	79.2	65.8	830.8	0.0095	86.9	98.3	G
1TY-1225-36A	135	78.2	54.5	698	0.0088	79	88	G
1TY-1225-40A	135	78.1	58.4	747	--	--	90	1/2 W
1TY-1225-7B	135	77.8	58.6	754	--	--	86	W
2TY-1225-5H	135	77.5	55.2	712	0.0084	85	90	G
2TY-1226-7A	135	77.7	59.0	758	--	--	92	1/2 W
2TY-1226-10B	135	78.1	50.4	646	0.0077	84	90	G

a - G = gage section one inch from tabs

1/2 W = between tab end and 1/2 width from tab end

b - Numerous horizontal jumps in the σ - ϵ curve accompanied by popping sounds; failure strain undefined

TABLE 32a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY LAMINATE L2, TRANSVERSE - T300/5208

Specimen ID	Temperature °F	Average Area, in.^{2}	Ultimate Load, P_{ult}, kip	Ultimate Stress, σ_{ult}, ksi	Ultimate Strain, ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure, E_{sf}, psi x 10^6	Secant Modulus at 17 ksi E_{s17}, psi x 10^6	Failure[a] Location
1TY1225-11E	-65	0.1230	4.9	39.6	0.0147	2.6	2.8	G
1TY1225-15E	-65	0.1226	5.0	40.6	0.0151	2.7	2.9	G
2TY1226-1D	-65	0.1210	4.6	38.2	0.0143	2.6	2.8	G
2TY1225-13C	72	0.1215	4.0	32.7	0.0137 [b]	2.4	2.5	G
2TY1225-13E	72	0.1220	4.2	34.1	0.0132 [c]	2.5	2.6	G
2TY1226-13F	72	0.1214	4.2	34.6	0.0139	2.5	2.8	G
2TY1226-2C	200	0.1199	3.8	32.0	0.0132	2.4	2.6	G
2TY1226-5D	200	0.1210	3.9	32.6	0.0144	2.3	2.7	G
2TY1226-19E	200	0.1235	4.2	34.0	0.0207	1.6	2.5	G
1TY1225-4F	275	0.1219	3.4	28.3	0.0131	2.2	2.5	G
2TY1225-17E	275	0.1221	3.7	30.0	0.0142	2.1	2.4	G
2TY1226-10D	275	0.1218	3.7	30.4	0.0136	2.2	2.6	G
2TY1226-7F	275	0.1219	3.8	30.9	0.0136	2.3	2.6	G
2TY1226-12F	275	0.1220	3.8	30.8	0.0143	2.2	2.5	G
2TY1226-14F	275	0.1209	3.7	30.4	0.0133	2.3	2.6	G

a - G - gage section one inch from tabs.

b - Strain at max stress, curve had flat topped region (max strain 0.0158)

c - Strain at max stress, curve had flat topped region (max strain 0.0156)

TABLE 32b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY LAMINATE L2, TRANSVERSE - T300/5208

Specimen ID	Temperature °C	Average Area, mm^2	Ultimate Load, P_{ult}, kN	Ultimate Stress, σ_{ult}, MPa	Ultimate Strain, ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure, E_{sf}, GPa	Secant Modulus at 117 MPa E_{s117}, GPa	Failure Location [a]
1TY1225-11E	-54	79.4	21.8	273.0	0.0154	17.9	19.3	G
1TY1225-15E	-54	79.1	22.2	279.9	0.0151	18.6	20.0	G
2TY1226-1D	-54	78.1	20.5	263.4	0.0144	17.9	19.3	G
2TY1225-13C	22	78.4	17.8	225.4	0.0137 [b]	16.6	17.2	G
2TY1225-13E	22	78.7	18.7	235.1	0.0132 [c]	17.2	17.9	G
2TY1226-13F	22	78.3	18.7	238.6	0.0139	17.2	19.3	G
2TY1226-2C	93	77.4	16.9	220.6	0.0132	16.6	17.9	G
2TY1226-5D	93	78.1	17.3	224.8	0.0144	15.9	18.6	G
2TY1226-19E	93	79.7	18.7	234.4	0.0207	11.0	17.2	G
1TY1225-4F	135	78.6	15.1	195.1	0.0131	15.2	17.2	G
2TY1225-17E	135	78.8	16.4	206.8	0.0142	14.5	16.5	G
2TY1226-10D	135	78.6	16.4	209.6	0.0136	15.2	17.9	G
2TY1226-7F	135	78.6	16.9	213.0	0.0136	15.9	17.9	G
2TY1226-12F	135	78.7	16.9	212.4	0.0143	15.2	17.2	G
2TY1226-14F	135	78.0	16.4	209.6	0.0133	15.9	17.9	G

a - G - gage section one inch from tabs.

b - Strain at max stress, curve had flat topped region (max strain 0.0158).

c - Strain at max stress, curve had flat topped region (max strain 0.0156).

TABLE 33a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR WET LAMINATE L2, TRANSVERSE - T300/5208

Specimen ID	Temperature ^{o}F	Average Area, $in.^2$	Ultimate Load, P_{ult}, kip	Ultimate Stress, σ_{ult}, ksi	Ultimate Strain, ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure, E_{sf}, psi x 10^6	Secant Modulus, at 17 ksi, E_{s17}, psi x 10^6	Failure Location[a]
1TY1225-13E	-65	0.1226	4.8	39.2	0.0152	2.6	3.0	G
2TY1225-15D		0.1222	4.8	39.0	0.0150	2.6	2.8	G
2TY1226-8C		0.1208	4.5	37.4	0.0140	2.7	2.9	G
1TY1225-19C	72	0.1215	4.4	36.1	0.0158	2.3	2.7	G
2TY1225-14E		0.1210	4.3	35.5	0.0146	2.4	2.7	G
2TY1226-16D		0.1218	4.4	36.0	0.0151	2.4	2.6	G
1TY1225-14E	200	0.1225	3.9	31.6	0.0148	2.1	2.5	G
2TY1225-12C		0.1217	3.8	30.7	0.0140	2.2	2.6	G
2TY1226-8D		0.1210	3.7	30.7	0.0131	2.3	2.5	G
1TY1225-7E	275	0.1225	3.3	27.0	0.0149	1.8	2.2	G
1TY1225-18E		0.1230	3.4	27.5	0.0145	1.9	2.3	G
2TY1225-17C		0.1218	3.4	28.3	0.0137	2.1	2.4	G
1TY1225-5C		0.1205	3.0	24.5	0.0135	1.8	2.1	G
1TY1225-7D		0.1225	3.1	25.3	0.0135	1.9	2.2	G
1TY1225-5E		0.1220	3.0	24.8	0.0134	1.9	2.2	G
1TY1225-9E		0.1235	3.1	25.3	0.0135	1.9	2.1	G
2TY1225-10E		0.1226	3.0	24.3	0.0132	1.8	2.0	G
2TY1226-15C		0.1212	2.9	23.8	0.0130	1.8	2.1	G

a - G - gage section one inch from tabs.

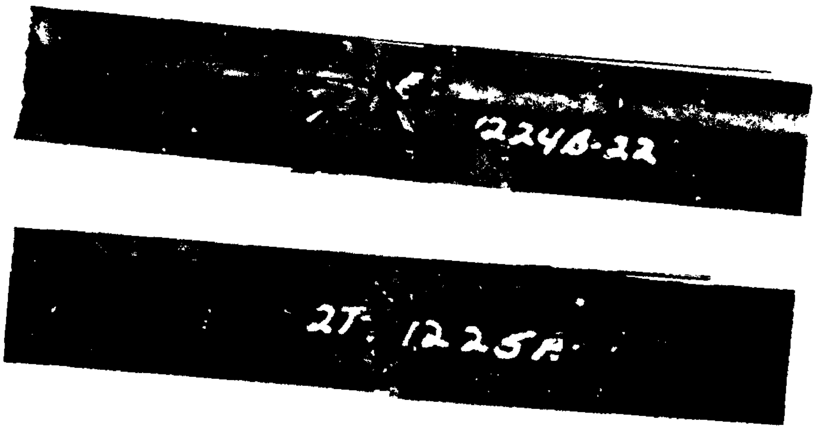
TABLE 33b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR WET LAMINATE L2, TRANSVERSE

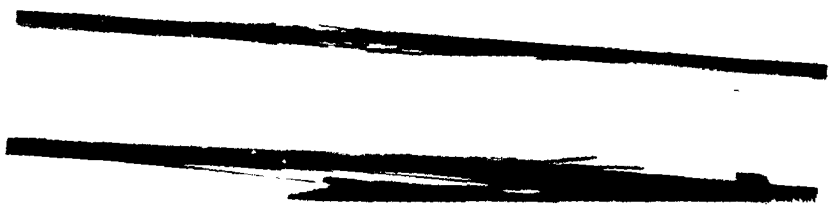
T300/5208

Specimen ID	Temperature °C	Average Area mm^2	Ultimate Load, P_{ult}, kN	Ultimate Stress, σ_{ult}, MPa	Ultimate Strain, ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 117 MPa E_{s117}, GPa	Failure Location[a]
1TY1225-13E	-54	79.1	21.4	270.3	0.0152	17.9	20.7	G
2TY1225-15D		78.8	21.4	268.9	0.0150	17.9	19.3	G
2TY1226-8C		77.9	20.0	257.9	0.0140	18.6	20.0	G
1TY1225-19C	22	78.4	19.6	248.9	0.0158	15.9	18.6	G
2TY1225-14E		78.1	19.1	244.8	0.0146	16.5	18.6	G
2TY1226-16D		78.6	19.6	248.2	0.0151	16.5	17.9	G
1TY1225-14E	93	79.0	17.3	217.9	0.0148	14.5	17.2	G
2TY1225-12C		78.5	16.9	211.7	0.0140	15.2	17.9	G
2TY1226-8D		78.1	16.5	211.7	0.0131	15.9	17.2	G
1TY1225-7E	135	79.0	14.7	186.2	0.0149	12.4	15.2	G
1TY1225-18E		79.4	15.1	189.6	0.0145	13.1	15.9	G
2TY1225-17C		78.6	15.1	195.1	0.0137	14.5	16.5	G
1TY-1225-5C		77.7	13.2	169	0.0135	12	14	G
1TY-1225-7D		79.0	13.8	174	0.0135	13	15	G
1TY-1225-5E		78.7	13.4	171	0.0134	13	15	G
1TY-1225-9E		79.7	13.9	174	0.0135	13	14	G
2TY-1225-10E		79.1	13.3	168	0.0132	12	14	G
2TY-1226-15C		78.2	12.8	164	0.0130	12	14	G

a - G = gage section one inch from tabs.

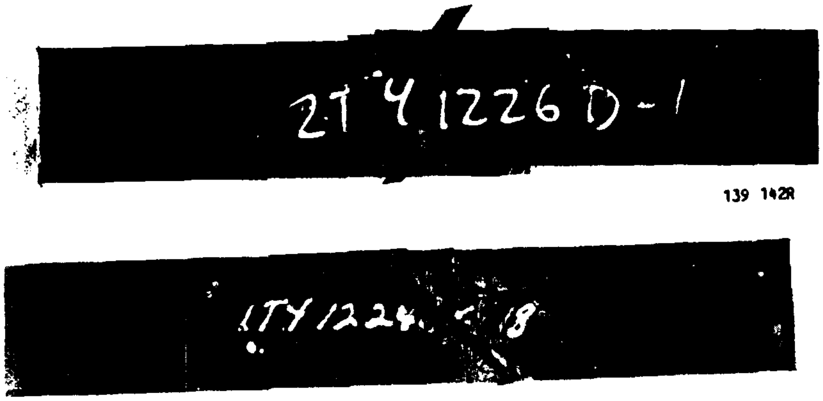


a. Side view, coupons 1TY1224-22B (L1L) and 2TY1225-1A (L2L) 139 147R



b. Edge view, coupons 1TY1224-22B (L1L) and 2TY1225-1A (L2L) 139 148R

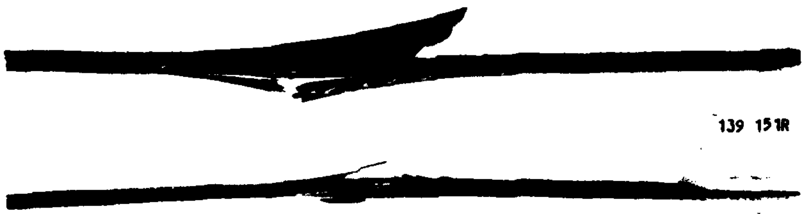
Figure 75. - Representative coupons failed in fully supported compression at -54°C (-65°F) after conditioning at 22°C (72°F)/40% RH.



139 142R

139 146R

a. Side view, coupons 2TY1226-1D (L2T) and 1TY1224-18E (L1T)

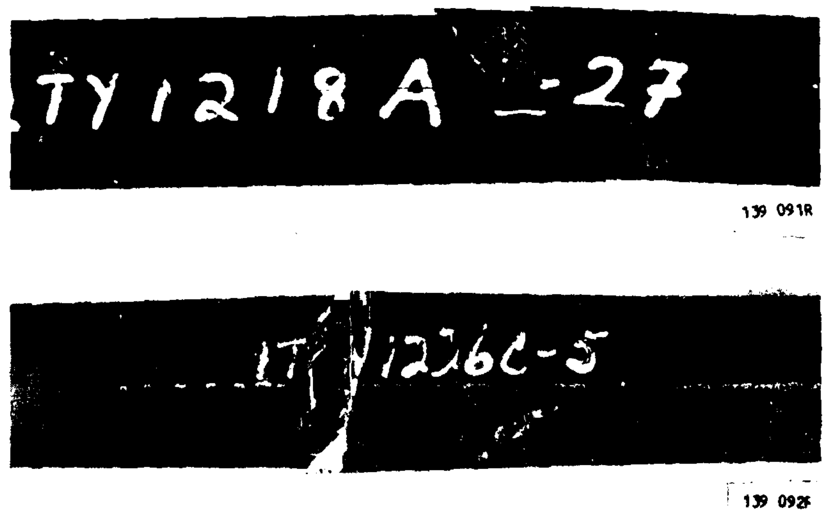


139 151R

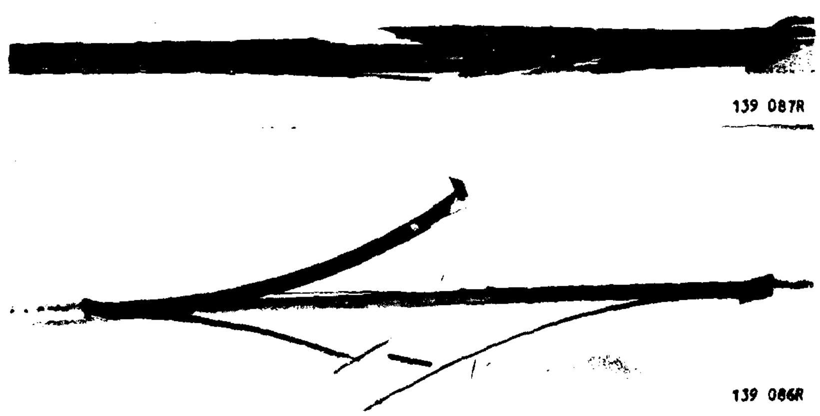
139 149R

b. Edge view, coupons 1TY1226-1D (L2T) and 1TY1224-18E (L1T)

Figure 76. - Representative coupons failed in fully supported compression at -54°C (-65°F) after conditioning at 22°C (72°F)/40% RH.

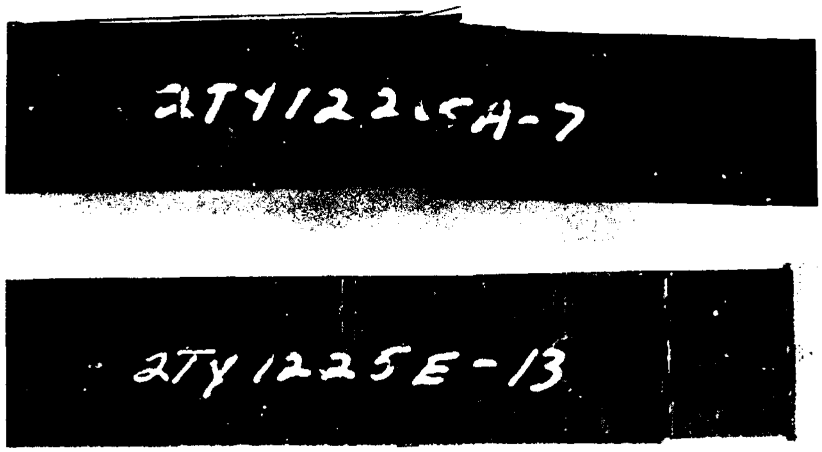


a. Side view, coupons 1TY1218-27A (L1L) and 1TY1226-5C (L1T)



b. Edge view, coupons 2TY1218-27A (L1L) and 1TY1226-5C (L1T)

Figure 77. - Representative coupons failed in fully supported compression at 22°C (72°F) after conditioning at 22°C (72°F)/40% RH.



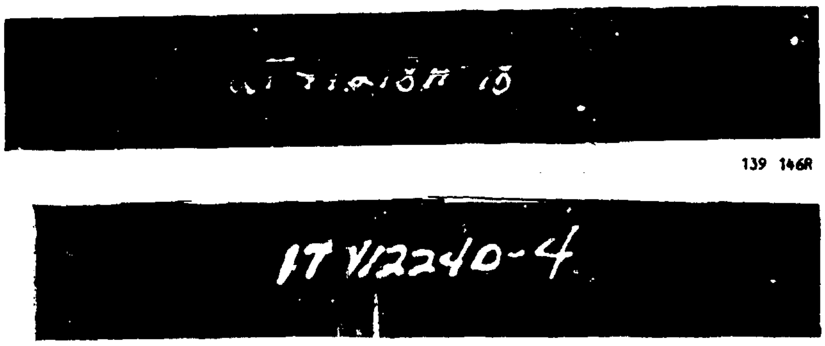
139 093R

a. Side view, coupons 1TY1225-7A (L2L) and 1TY1225-13E (L2T)

139 088R

b. Edge view, coupons 1TY1225-7A (L2L) and 1TY1225-13E (L2T)

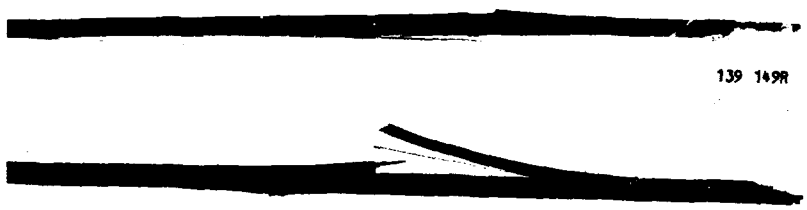
Figure 78. - Representative coupons failed in fully supported compression at 22°C (72°F) after conditioning at 22°C (72°F)/40% RH.



139 146R

139 142R

a. Side view, coupons 1TY1218-18A (L1L) and 1TY1224-4D (L1T)

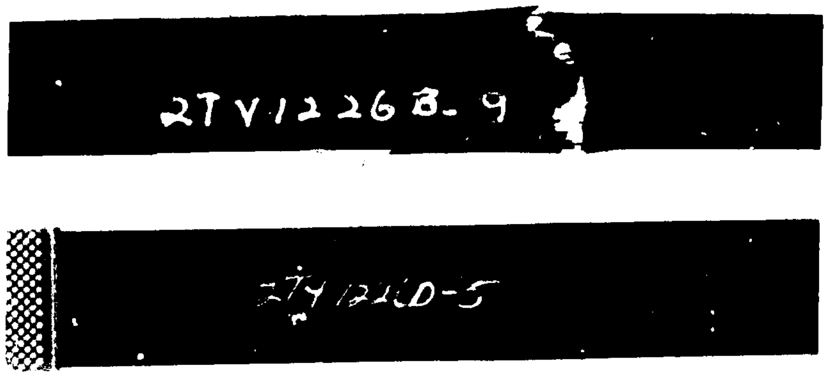


139 149R

139 151R

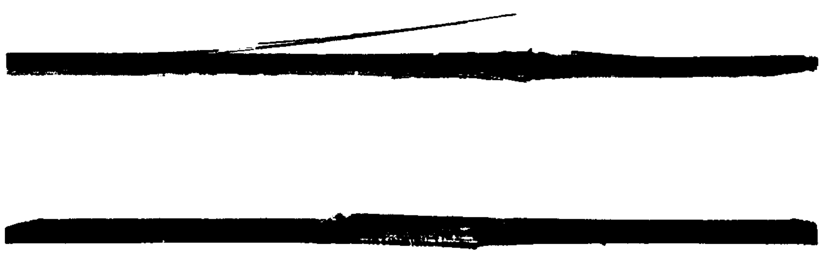
b. Edge view, coupons 2TY1218-18A (L1) and 1TY1224-4D (L1T)

Figure 79. - Representative coupons failed in fully supported compression at 93°C (200°F) after conditioning at 22°C (72°F)/40% RH.



139 143R

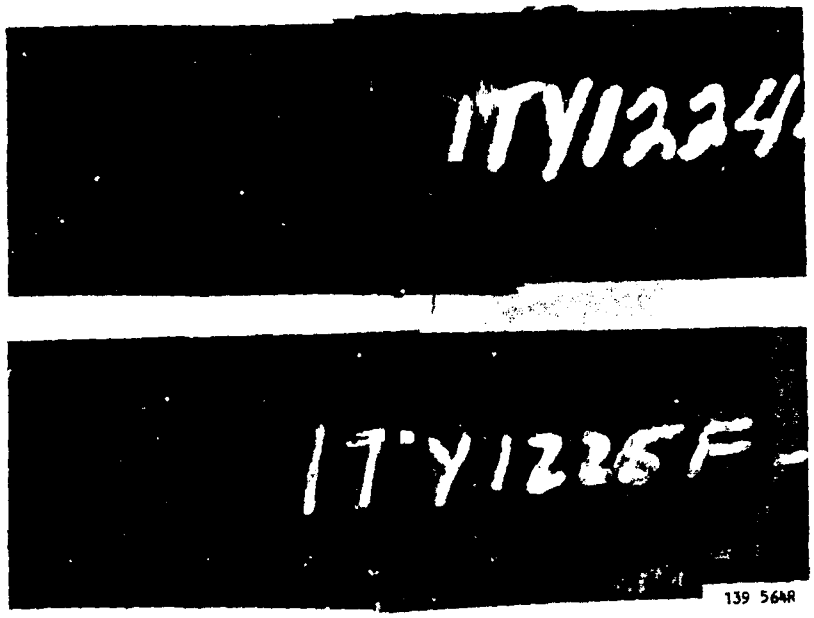
a. Side view, coupons 2TY1226-9B (L2L) and 2TY1226-5D (L2T)



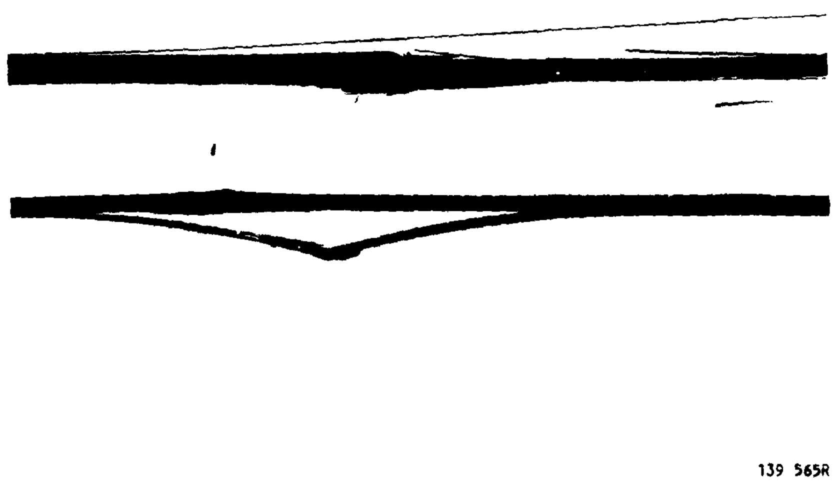
139 150R

b. Edge view, coupons 2TY1226-9B (L2L) and 2TY1226-5D (L2T)

Figure 80. - Representative coupons failed in fully supported compression at 93°C (200°F) after conditioning at 22°C (72°F)/40% RH.

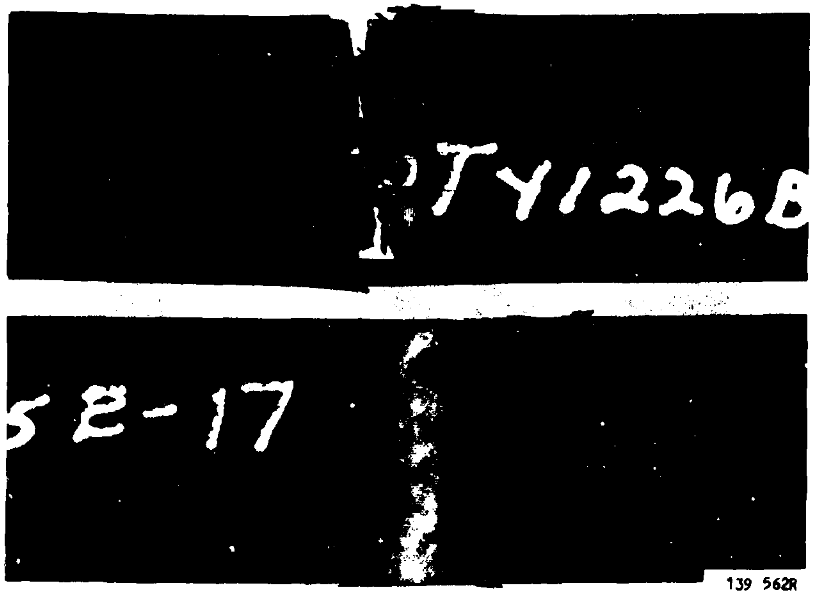


a. Side view, coupons 1TY1224-30A (L1L) and 1TY1226-3F (L1T)

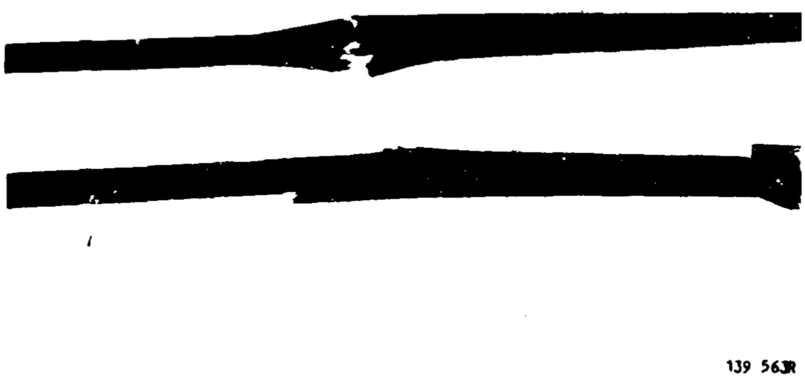


b. Edge view, coupons 1TY1224-30A (L1L) and 1TY1226-3F (L1T)

Figure 81. - Representative coupons failed in fully supported compression at 135°C (275°F) after conditioning at 22°C (72°F)/40% RH.



a. Side view, coupons 2TY1226-23B (L2L) and 2TY1225-17E (L2T)



b. Edge view, coupons 2TY1226-23B (L2L) and 2TY1225-17E (L2T)

Figure 82. - Representative coupons failed in fully supported compression at 135°C (275°F) after conditioning at 22°C (72°F)/40% RH.

that the cutouts were not inducing premature failure, new support platens without holes were fabricated for use in evaluations of the unidirectional U1L specimens.

4.6.2 Laminate U1 - T300/5208

Testing of unidirectional 0° laminates in compression is difficult since the slightest eccentricity will result in failure due to instability. Despite numerous trials and modifications in support fixturing, failures of the 0°, longitudinal laminate (U1L) continued to occur at the tab ends. New support platens without cutouts for extensometer points, squaring of end tabs, and special bonding of tabs without adhesive fillets to allow complete support of the coupon did not significantly influence the performance. Failure stress ranged from 731 MPa (106 ksi) to 1242 MPa (180 ksi), with an average for T300/5208 of 988 MPa (143 ksi) (12 coupons). Failures were "good" in that they appeared to be shear/crushing failures rather than instability failures. The brooming end-failures were similar to those generally obtained in Celanese compression tests. However, the compression stress-strain data for both U1L and U1T fully-supported tests showed noticeable non-linearity. Representative curves are presented in Figure 83 through 86.

The fully supported compression test data obtained at four temperatures for the T300/5208 laminates U1,Longitudinal and transverse respectively, dry conditioned at $22^{\circ}C$ ($72^{\circ}F$) and 40% R.H. and wet conditioned at $82^{\circ}C$ ($180^{\circ}F$) and 90% R.H., are presented in Tables 34 and 35. Since compression stress-strain curves for both laminates were non-linear with smooth continuous curves, secant moduli were evaluated at maximum stress for both laminates at 17 ksi for U1-transverse (U1T), and 70 ksi for U1-longitudinal (U1L). As was the case for the quasi-isotropic laminate L1 and the 67% 0° laminate L2 conditioned at $22^{\circ}C$ ($72^{\circ}F$) and 40% R.H., there is no significant change in the modulus for either of these two laminate types over the temperature range of $-54^{\circ}C$ ($-65^{\circ}F$) to $135^{\circ}C$($275^{\circ}F$). Strength generally appears to decrease with increasing temperature. This trend is especially noticeable in tests transverse to the fiber (laminate U1T); for this case, non-linearity of the stress-strain curve also becomes quite pronounced at the elevated temperature (Figure 86). Moisture

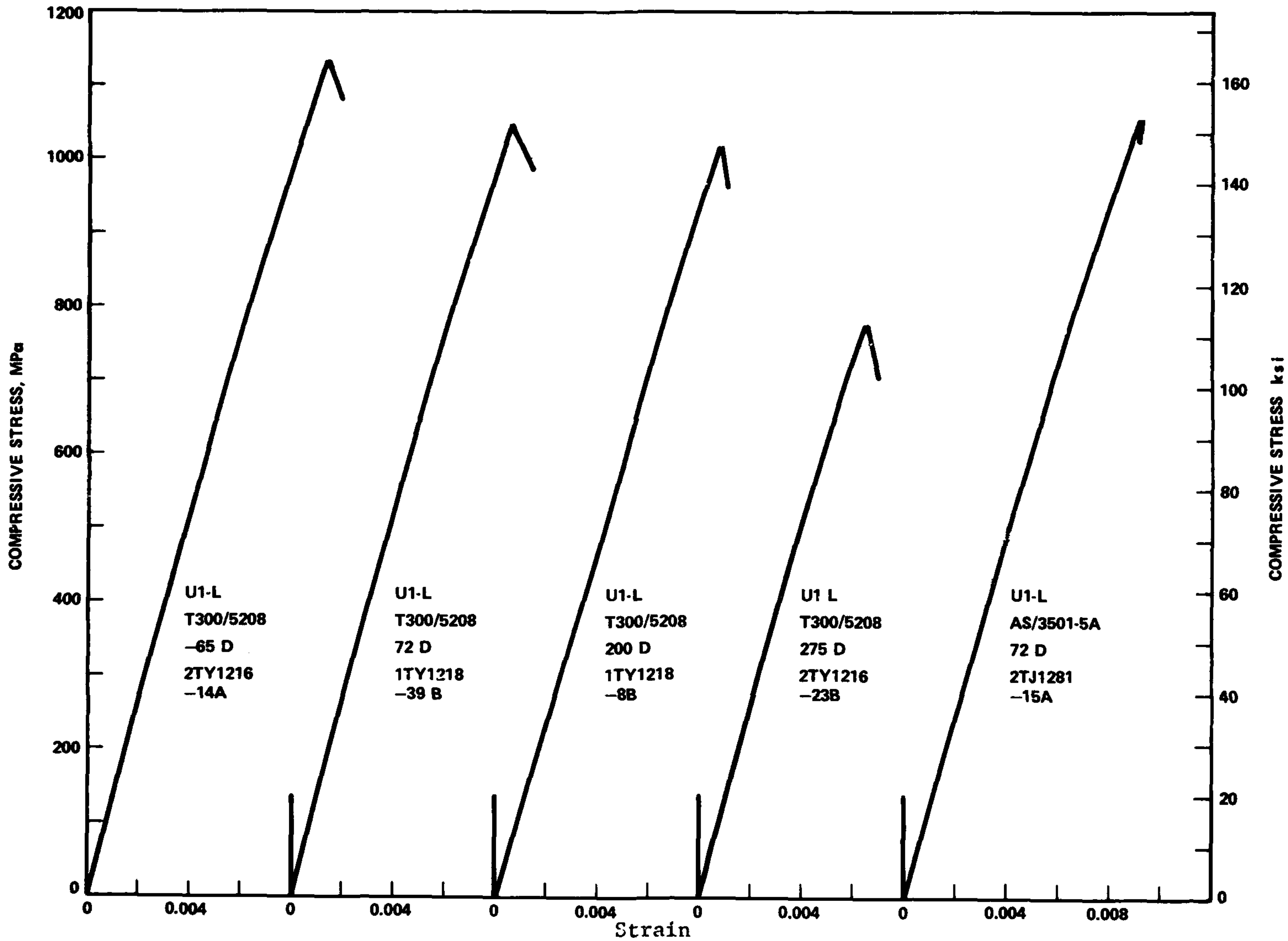


Figure 83. - Representative compressive stress-strain curves obtained on unidirectional laminate in fiber direction, tested dry.

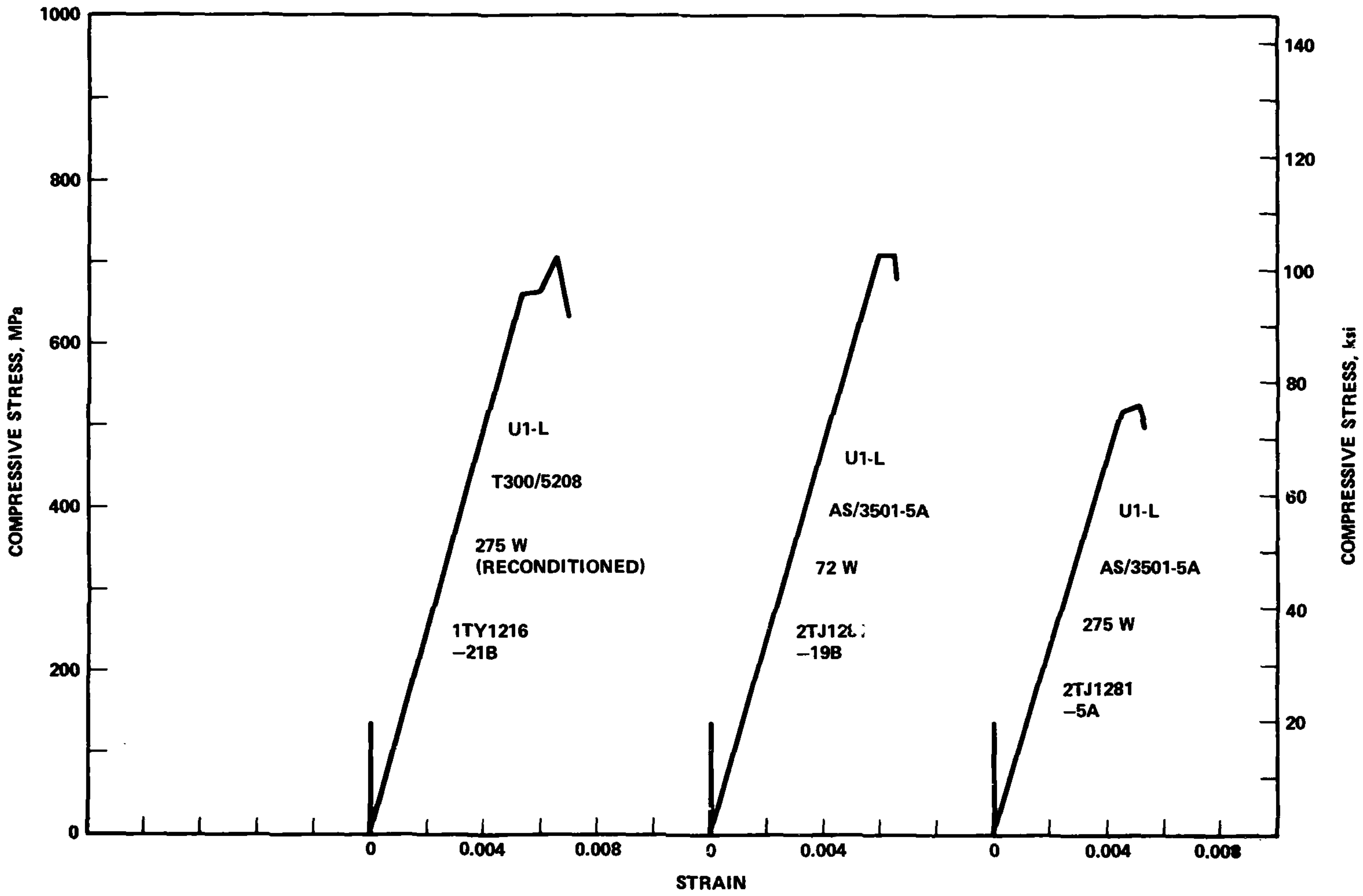


Figure 84. - Representative compressive stress-strain curves obtained on unidirectional laminate in fiber direction, tested wet.

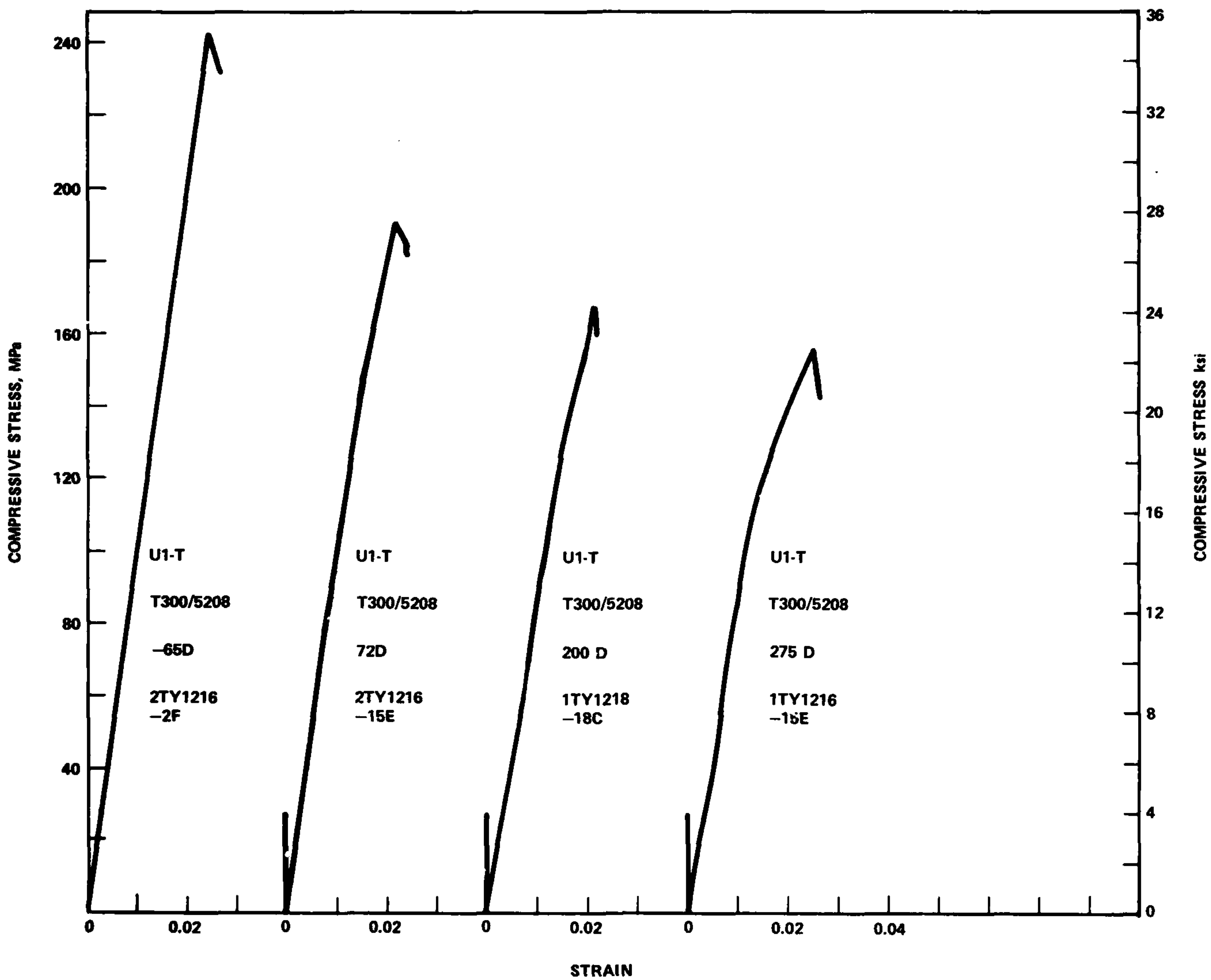


Figure 85. - Representative compressive stress-strain curves obtained on unidirectional laminate at 90° to the fiber axis, tested dry.

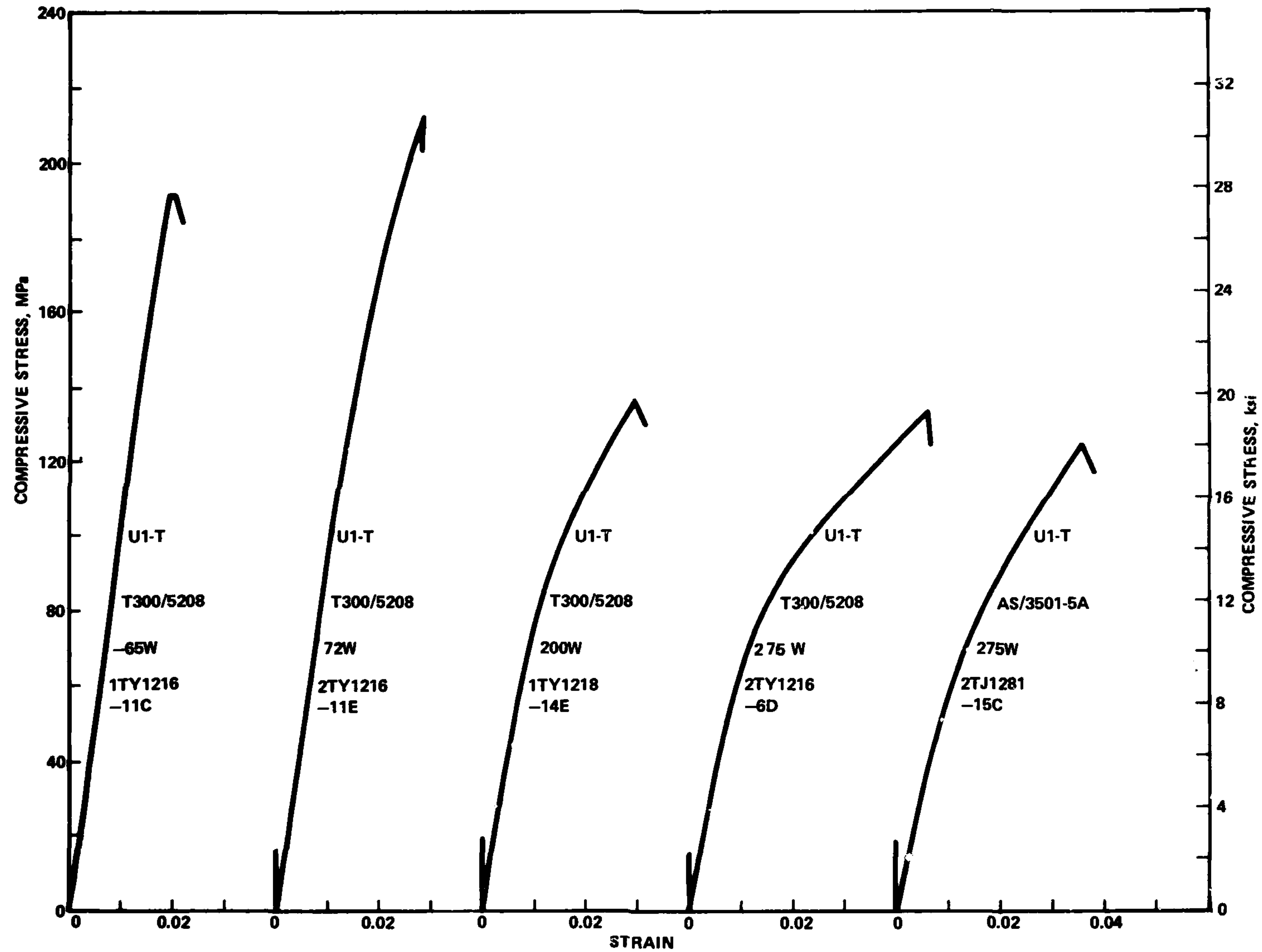


Figure 86. - Representative compressive stress-strain curves obtained on unidirectional laminate at 90° to the fiber axis, tested wet.

TABLE 34a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY AND WET LAMINATE U1, LONGITUDINAL - T300/5208

Specimen ID	Temperature °F	Average Area in.^{2}	Ultimate Load, P_{ult}, kip	Ultimate Stress, σ_{ult}, ksi	Ultimate Strain, ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure, E_{sf}, psi x 10^6	Secant Modulus, at 70 ksi E_{s70} psi x 10^6	Failure Location[a]
1TY1216-5A	-65D	0.0805	16.5	204.7	-[b]	-[b]	-[b]	1/2 W
1TY1216-13B		0.0819	16.1	196.4	-[b]	-[b]	-[b]	1/2 W
2TY1216-11A		0.0809	14.2	175.8	0.0093	17.6	19.1	G
2TY1216-14A		0.0798	13.0	163.4	0.0097	18.1	20.6	G
2TY1216-24A		0.0805	12.2	151.6	-[b]	-[b]	-[b]	1/2 W
2TY1216-21B		0.0812	12.1	149.6	-[b]	-[b]	-[b]	1/2 W
1TY1216-15A	72D	0.0818	11.3	138.0	0.0080	17.2	17.5	1/2 W
1TY1216-19A		0.0823	9.1	110.6	0.0060	18.5	19.2	1/2 W
1TY1216-25A		0.0812	12.1	148.5	0.0087	17.0	18.1	1/2 W
1TY1216-26A		0.0816	8.7	106.3	0.0055	19.2	19.6	1/2 W
1TY1216-20B		0.0826	11.1	134.0	0.0075	17.8	19.0	1/2 W
1TY1216-28B		0.0822	14.8	179.8	-[b]	-[b]	-[b]	1/2 W
2TY1216-18A		0.0807	12.8	159.0	0.0092	17.3	19.6	1/2 W
2TY1216-28A		0.0807	11.0	136.9	0.0081	17.0	19.0	1/2 W
1TY1218-4A		0.0800	11.8	147.9	0.0079	18.7	19.8	G
1TY1218-28A		0.0792	11.1	140.4	-[b]	-[b]	-[b]	1/2 W
1TY1218-30A		0.0783	13.1	167.8	-[c]	-[c]	-[c]	1/2 W
1TY1218-39B		0.0801	12.1	151.1	0.0086	17.6	18.9	1/2 W
1TY1216-9A	200D	0.0816	12.1	148.0	-[b]	-[b]	-[b]	1/2 W
1TY1216-16A		0.0815	10.0	122.4	-[b]	-[b]	-[b]	1/2 W
2TY1216-1A		0.0795	9.1	115.0	0.0064	17.9	18.9	1/2 W
1TY1218-8B		0.0792	11.7	147.2	0.0086	17.2	18.9	1/2 W
1TY1218-24B		0.0821	12.3	149.4	-[b]	-[b]	-[b]	1/2 W
1TY1216-3A	275D	0.0821	9.4	114.5	-[b]	-[b]	-[b]	1/2 W
1TY1216-12A		0.0815	8.7	107.1	-[b]	-[b]	-[b]	1/2 W
1TY1216-32B		0.0808	8.9	110.2	-[b]	-[b]	-[b]	1/2 W
2TY1216-23B		0.0820	9.2	112.2	0.0063	17.9	18.9	1/2 W
1TY1216-39B	72W	0.0792	11.9	150.3	-[b]	-[b]	-[b]	1/2 W
2TY1216-2A		0.0804	13.0	161.7	-[b]	-[b]	-[b]	1/2 W
1TY1218-26A		0.0792	11.6	146.5	-[b]	-[b]	-[b]	1/2 W
1TY1216-4A	275W	0.0809	5.6	69.2	-[b]	-[b]	-[b]	G
1TY1216-34A		0.0809	6.2	76.4	-[b]	-[b]	-[b]	1/2 W
2TY1216-5B		0.0820	5.9	71.7	-[b]	-[b]	-[b]	1/2 W
1TY1216-1A		0.0811	7.2	89.0	0.0051	17.4	18.2	G
1TY1216-33A		0.0811	6.9	84.6	0.0047	18.1	19.9	G
1TY1216-5B		0.0816	6.6	80.6	-	-	-	1/2 W
1TY1216-40B		0.0813	8.0	98.2	-	-	-	1/2 W
2TY1216-16A		0.0802	8.5	106.2	0.0066	16.1	17.7	G
1TY1218-22A		0.0805	5.2	64.6	-	-	-	1/2 W

a - G - gage section one inch from tabs. 1/2 W - between tab end and 1/2 width from tab end.

b - Only crosshead deflection was measured, strain determination inaccurate.

c - Could not be determined due to operator error.

AD-A085 167 LOCKHEED-CALIFORNIA CO BURBANK F/G 11/4
THE EFFECT OF ENVIRONMENT ON THE COMPRESSIVE STRENGTHS OF LAMIN--ETC(U)
DEC 79 K N LAURAITIS, P E SANDORFF F33615-77-C-5140
UNCLASSIFIED LR-28508-8 AFML -TR-79-4179 NL

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TABLE 34b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY AND WET LAMINATE U1, LONGITUDINAL - T300/5208

Specimen ID	Temperature °C	Average Area mm^2	Ultimate Load P_{ult}, kN	Ultimate Stress, σ_{ult}, MPa	Ultimate Strain, ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 483 MPa E_{s482} GPa	Failure Location[a]
1TY1216-5A	-54D	51.9	73.4	1411.4	-[b]	-[b]	-[b]	1/2 W
1TY1216-13B		52.8	71.6	1354.1	-[b]	-[b]	-[b]	1/2 W
2TY1216-11A		52.2	63.2	1212.1	0.0093	121.3	131.7	G
2TY1216-14A		51.5	57.8	1126.6	0.0097[b]	124.8[b]	142.0[b]	G
2TY1216-24A		51.9	54.3	1045.2	-[b]	-[b]	-[b]	1/2 W
2TY1216-21B		52.4	53.8	1031.5	-	-	-	1/2 W
1TY1216-15A	22D	52.8	50.3	951.5	0.0080	118.6	120.7	1/2 W
1TY1216-19A		53.1	40.5	762.6	0.0060	127.6	132.4	1/2 W
1TY1216-25A		52.4	53.8	1023.9	0.0087	117.2	124.8	1/2 W
1TY1216-26A		52.6	38.7	732.9	0.0055	132.4	135.1	1/2 W
1TY1216-20B		53.3	49.4	923.9	0.0075[b]	122.7[b]	131.0[b]	1/2 W
1TY1216-28B		53.0	65.8	1239.7	-	-	-	1/2 W
2TY1216-18A		52.1	56.9	1096.3	0.0092	119.3	135.1	1/2 W
2TY1216-28A		52.1	48.9	943.9	0.0081	117.2	131.0	1/2 W
1TY1218-4A		51.6	52.5	1019.7	0.0079[b]	128.9[b]	136.5[b]	G
1TY1218-28A		51.1	49.4	968.0	-	-	-	1/2 W
1TY1218-30A		50.5	58.3	1156.9	-[c]	-[c]	-[c]	1/2 W
1TY1218-39B		52.1	53.8	1041.8	0.0086	121.3	130.3	1/2 W
1TY1216-9A	93D	52.6	53.8	1020.4	-[b]	-[b]	-[b]	1/2 W
1TY1216-16A		52.6	44.5	843.9	-[b]	-[b]	-[b]	1/2 W
2TY1216-1A		51.3	40.5	792.9	0.0064	123.4	130.3	1/2 W
1TY1218-8B		51.1	52.0	1014.9	0.0086[b]	118.6[b]	130.3[b]	1/2 W
1TY1218-24B		53.0	54.7	1030.1	-	-	-	1/2 W
1TY1216-3A	135D	53.0	41.8	789.4	-[b]	-[b]	-[b]	1/2 W
1TY1216-12A		52.6	38.7	738.4	-[b]	-[b]	-[b]	1/2 W
1TY1216-32B		52.1	39.6	759.8	-[b]	-[b]	-[b]	1/2 W
2TY1216-23B		52.9	40.9	773.6	0.0063	123.4	130.3	1/2 W
1TY-1216-39B	22W	51.1	52.9	1036.3	-[b]	-[b]	-[b]	1/2 W
2TY-1216-2A		61.9	57.8	1114.9	-[b]	-[b]	-[b]	1/2 W
1TY-1218-26A		51.1	51.6	1010.1	-[b]	-[b]	-[b]	1/2 W
1TY-1216-4A	135W	52.2	24.9	477.1	-[b]	-[b]	-[b]	G
1TY-1216-34A		52.2	27.6	526.8	-[b]	-[b]	-[b]	1/2 W
2TY-1216-5B		52.9	26.2	494.3	-[b]	-[b]	-[b]	1/2 W
1TY-1216-1A		52.3	32.1	614	0.0051	120	130	G
1TY-1216-33A		52.3	30.5	583	0.0047	120	140	G
1TY-1215-5B		52.6	29.3	556	--	--	--	1/2 W
1TY-1216-40B		52.5	35.5	677	--	--	--	1/2 W
2TY-1216-16A		51.7	37.9	732	0.0066	110	120	G
1TY-1218-22A		51.9	23.1	445	--	--	--	1/2 W

a - G - gage section one inch from tabs. 1/2 W - between tab end and 1/2 width from tab end.

b - *Only crosshead deflection was measured, strain determination inaccurate.*

c - Could not be determined due to operator error.

TABLE 35a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY AND WET LAMINATE U1, TRANSVERSE - T300/5208

Specimen ID	Temperature °F	Average Area in.^{2}	Ultimate Load P_{ult}, kip	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Secant Modulus, at 17 ksi E_{s17} psi x 10^6	Failure Location[a]
2TY1216-2F	-65D	0.0797	2.8	35.2	0.0246	1.4	1.54	G
1TY1218-16E		0.0815	2.9	35.3	0.0261	1.4	1.49	G
1TY1218-18E		0.0818	2.3	28.4	0.0210	1.4	1.43	G
2TY1216-3C	72D	0.0793	2.9	36.9	0.0306	1.2	1.45	G
2TY1216-15E		0.0793	2.2	27.7	0.0222	1.2	1.42	1/2 W
2TY1216-10F		0.0798	2.2	26.9	0.0204	1.3	1.44	G
1TY1218-1F		0.0803	2.3	28.5	0.0220	1.3	1.37	
1TY1216-1E	200D	0.0804	1.6	20.3	0.0174	1.2	1.24	G
1TY1218-18C		0.0808	2.0	24.2	0.0222	1.1	1.27	W
1TY1218-4E		0.0806	2.4	29.7	0.0306	1.0	1.26	G
1TY1216-6C	275D	0.0809	1.6	19.4	0.0192	1.0	1.15	G
1TY1216-15E		0.0820	1.8	22.6	0.0258	0.9	1.16	G
2TY1216-4C		0.0791	2.0	25.0	0.0294	0.8	1.20	1/2 W
1TY1216-3C	-65W	0.0810	1.51	18.6	0.0133	1.51	1.51	G
1TY1218-11C		0.0802	2.23	27.8	0.0192	1.45	1.51	G
1TY1218-13C		0.0795	2.17	27.3	0.0195	1.40	1.51	W
1TY1216-4F	72W	0.0810	2.33	28.7	0.0258	1.11	1.30	G
2TY1216-11E		0.0798	2.47	30.9	0.0288	1.07	1.32	W
2TY1216-9F		0.0800	-	-	-	-	1.35	-
1TY1216-16D	200W	0.0829	1.62	19.5	0.0261	0.75	0.78	G
1TY1218-9D[b]		0.0796	1.91	23.9	-	-	0.99	G
1TY1218-14E		0.0813	1.61	19.8	0.0291	0.68	0.78	G
1TY1217-10F	275W	0.0808	1.48	18.3	0.0306	0.60	0.60	G
2TY1216-13E		0.0797	1.57	19.7	0.0456	0.43	0.60	G
1TY1218-6D		0.0797	1.54	19.3	0.0350	0.55	0.61	G
1TY1216-10E		0.0816	1.21	14.8	0.0257	0.58	-	1/2 W
2TY1216-10E		0.0798	1.53	19.2	0.0339	0.57	0.6	G
1TY1218-2F		0.0808	1.40	17.3	0.0276	0.63	0	W

a - G - gage section one inch from tabs. W - between 1/2 and 1 specimen width (1-inch) away from tab.
1/2 W - between tab end and 1/2 width from tab end.
b - Overheated to 275°F, cooled to 200°F and tested.

TABLE 35b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY AND WET LAMINATE U1, TRANSVERSE - T300/5208

Specimen ID	Temperature °C	Average Area mm^2	Ultimate Load, P_{ult}, kN	Ultimate Stress, σ_{ult}, MPa	Ultimate Strain, ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 117 MPa E_{s117} GPa	Failure[a] Location
2TY1216-2F	-54D	51.4	12.5	242.7	0.0246	9.7	10.6	G
1TY1218-16E		52.6	12.9	243.4	0.0261	9.7	10.3	G
1TY1218-18E		52.8	10.2	195.8	0.0210	9.7	9.9	G
2TY1216-3C	22D	51.2	12.9	254.4	0.0306	8.3	10.0	G
2TY1216-15E		51.2	9.8	191.0	0.0222	8.3	9.8	1/2 W
2TY1216-10F		51.5	9.8	185.5	0.0204	9.0	9.9	G
1TY1218-1F		51.8	10.2	196.5	0.0220	9.0	9.4	
1TY1216-1E	93D	51.9	7.1	140.0	0.0174	8.3	8.5	G
1TY1218-18C		52.1	8.9	166.9	0.0222	7.6	8.8	W
1TY1218-4E		52.0	10.7	204.9	0.0306	6.9	8.7	G
1TY1216-6C	135D	52.2	7.1	133.8	0.0192	6.9	7.9	G
1TY1216-15E		52.9	8.0	155.8	0.0258	6.2	8.0	G
2TY1216-4C		51.0	8.9	172.4	0.0294	5.5	8.3	1/2 W
1TY-1216-3C	-54W	52.3	6.72	128	0.0123	10.4	10.4	G
1TY-1218-11C		51.7	9.92	192	0.0192	10.0	10.3	W
1TY-1218-13C		51.3	9.65	188	0.0195	9.7	10.3	W
1TY-1216-4F	22W	52.3	10.36	198	0.0258	7.7	9.0	G
2TY-1216-11E		51.5	10.99	213	0.0288	7.4	9.1	W
2TY-1216-9F		51.6	--	--	--	--	9.3	-
1TY-1216-16D	93W	53.5	7.21	134	0.0261	5.2	5.4	G
1TY-1218-9D *		51.4	8.50	165	--	--	6.8	G
1TY-1218-14E		52.5	7.16	137	0.0291	4.7	5.4	G
1TY-1216-10F	135W	52.1	6.58	126	0.0306	4.1	4.1	G
2TY-1216-13E		51.4	6.98	136	0.0456	3.0	4.0	G
1TY-1218-6D		51.4	6.85	133	0.0350	3.8	4.2	G
1TY-1216-10E		52.6	5.4	102	0.0256	4.0	--	1/2 W
2TY-1216-10E		51.5	6.8	132	0.0339	3.9	3.9	G
1TY-1218-2F		52.1	6.2	119	0.0276	4.3	--	W

* Overheated to 135°C, cooled to 93°C and tested.

a - G - gage section one inch from tabs. W - between 1/2 and 1 specimen width (1 inch) away from tab.
1/2 W - between tab end and 1/2 width from tab end.

further augments the deleterious effect of temperature in both U1L and U1T with the greater drop of nearly 50% from the room temperature dry condition evident for U1L.

4.6.3 Laminates L1, L2 and U1 - AS/3501-5A

The fully spported compression test data for AS/3501-5A obtained at 22°C (72°F) after dry conditioning in lab air, and at 135°C (275°F) after wet conditioning at 82°C (180°F) and 90% RH, are presented in Tables 36 through 40 for laminates L1, L2 and U1, both longitudinal and transverse. Compression stress-strain curves for all of these laminates were non-linear with a smooth continuous curve. Therefore, secant moduli were evaluated at maximum stress for all the laminates, and at 117 MPa (17 ksi) for L2-transverse (L2T) and U1-transverse (U1T), 241 MPa (34 ksi) for L1-longitudinal (L1L) and L1-transverse (L1T), and 483 MPa (70 ksi) for L2-longitudinal (L2L) and U1-longitudinal (U1L).

Unlike the T300/5208 material, AS/3501-5A tested at 135°C (275°F) after wet (90% RH, 82°C (180°F)) conditioning reveals a significant drop in modulus (approximately 12%) for laminates L1T, L1L and L2L and 30% for L2T when compared to those conditioned and tested in laboratory air (40% RH, 22°C (72°F)). The former three laminates also exhibit a decrease in strain to failure of 18%, 30% and 51%, respectively while the latter shows no change in failure strain. Strain to failure under the same conditions for T300/5208 material was observed to decrease 18% for L2L and 13% for L1L with no change evident for the corresponding transverse orientations. U1L and U1T also reveal a decrease in strain to failure for the elevated temperature wet condition compared to the room temperature dry results. The drop in the AS/3501-5A compressive strength for the 135°C (275°F) wet condition, as compared to the 22°C (72°F) dry condition, was greatest for laminates U1 and L2, both longitudinal and transverse with decreases ranging from 40% to 50%. Reduction in compressive strength for L1-longitudinal was 21% and 26% for the transverse orientation. These full platen-supported compression results for AS/3501-5A material are presented in Tables 36 through 40. Representative stress-strain curves for the unidirectional laminates are included in Figures 83, 84, and 86.

TABLE 36a

FULLY SUPPORTED COMPRESSION TEST DATA FOR DRY AND WET LAMINATE L1, LONGITUDINAL - AS/3501-5A

Temp. °F	Specimen ID	Average Area (in.^{2})	Ultimate Load P_{ult}, kip	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Secant Modulus at 35 ksi E_{s35}, psi x 10^6	Failure[a] Location
72D	1TJ1282-25A	.0857	6.8	78.9	-[b]	-[b]	7.0	G
	-13C	.0830	7.5	90.4	.0160	5.6	7.0	G
	-21C	.0847	6.8	79.8	.0136	5.9	6.8	G
275W	1TJ1282-8C	.0844	5.2	61.6	.0101	6.1	6.1	1/2 W
	-9C	.0843	5.0	59.3	.0100	5.9	6.1	G
	-29A	.0857	5.2	60.7	.0108	5.6	6.1	G

a - G - gage section one inch from tabs. 1/2 W - between tab end and 1/2 width from tab end.

b - Failure strain undefined.

TABLE 36b

FULLY SUPPORTED COMPRESSION TEST DATA FOR DRY AND WET LAMINATE L1, LONGITUDINAL AS/3501-5A

Temp. °C	Specimen ID	Average Area mm^2	Ultimate Load P_{ult}, kN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 241 MPa E_{s241}, GPa	Failure Location[a]
22D	1TJ1282-25A	55.3	30.2	544.0	–[b]	–[b]	48.3	G
	-13C	53.6	33.4	623.3	.0160	38.0	48.3	G
	-21C	54.6	30.2	550.2	.0136	40.7	46.9	G
135W	1TJ1282-8C	54.5	23.1	424.7	.0101	42.1	42.1	1/2 W
	-9C	54.4	22.2	408.9	.0100	40.7	42.1	G
	-29A	55.3	23.1	418.5	.0108	38.6	42.1	G

a – G = gage section one inch from tabs, 1/2 W = between tab end and 1/2 width from tab end.

b – Failure strain undefined.

TABLE 37a

FULLY SUPPORTED COMPRESSION TEST DATA FOR DRY AND WET LAMINATE L1, TRANSVERSE - AS/3501-5A

Temp. °F	Specimen ID	Average Area (in.^{2})	Ultimate Load P_{ult}, kip	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ε_{ult}, in./in. in 2 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Secant Modulus at 35 ksi E_{s35}, psi x 10^6	Failure Location[a]
72D	1TJ1282-12D	.0856	5.8	68.0	.0114	6.0	6.6	G
	-13E	.0846	6.0	70.7	.0119	6.0	7.0	G
	-8F	.0841	5.7	67.3	.0108	6.2	6.9	G
275W	1TJ1282-6D	.0870	4.4	50.9	.0090	5.7	6.0	G
	-14D	.0838	4.3	51.0	.0093	5.5	6.0	G
	-10E	.0876	4.6	51.5	.0096	5.4	6.0	G

a - G - gage section one inch from tabs

TABLE 37b

FULLY SUPPORTED COMPRESSION TEST DATA FOR DRY AND WET LAMINATE L1, TRANSVERSE - AS/3501-5A

Temp. ^oC	Specimen ID	Average Area mm^2	Ultimate Load P_{ult}, kN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 241 MPa E_{s241}, GPa	Failure[a] Location
22D	1TJ1282-12D	55.2	25.8	468.8	.0114	41.4	48.5	G
	-13E	54.6	26.7	487.5	.0119	41.4	48.3	G
	-8F	54.3	25.4	464.0	.0108	42.8	47.6	G
135W	1TJ1282-6D	56.1	19.6	350.9	.0090	39.3	41.4	G
	-14D	54.1	19.1	351.6	.0093	37.9	41.4	G
	-10E	56.5	20.5	355.1	.0096	37.2	41.4	G

a - G = gage section one inch from tabs

TABLE 38a

FULLY SUPPORTED COMPRESSION TEST DATA FOR DRY AND WET LAMINATE L2, LONGITUDINAL - AS/3501-5A

Temp. ^oF	Specimen ID	Average Area (in.^{2})	Ultimate Load P_{ult}, kip	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Secant Modulus at 70 ksi E_{s70}, psi x 10^6	Failure[a] Location
72D	1TJ1240-9B	.1253	17.3	138.0	.0120	11.5	12.6	W
	1TJ1283-16C	.1267	19.4	153.2	.0148	10.3	12.5	G
	2TJ1283-9A	.1279	15.8	123.5	-[b]	-[b]	12.9	G
275W	1TJ1283-1A	.1105	7.6	68.8	.0067	10.3	-[c]	1/2 W
	-2B	.1232	9.9	80.2	.0067	12.0	12.3	1/2 W
	-7B	.1270	8.7	68.5	.0063	10.9	-[c]	1/2 W

a - G - gage section one inch from tabs; 1/2 W - between tab end and 1/2 width from tab end.

b - Failure strain undefined.

c - Specimen failed at less than 70 ksi, E_{s70} could not be determined.

TABLE 38b

FULLY SUPPORTED COMPRESSION TEST DATA FOR DRY AND WET LAMINATE L2 LONGITUDINAL -AS/3501-5A

Temp. °C	Specimen ID	Average Area mm^2	Ultimate Load P_{ult}, kN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 483 MPa E_{s483}, GPa	Failure Location[a]
22D	1TJ1240-9B	80.8	77.0	951.5	.0120	79.3	86.9	W
	1TJ1283-16C	81.7	86.3	1056.3	.0148	71.0	86.2	G
	2TJ1283-9A	82.5	70.3	851.5	-[b]	-[b]	88.9	G
135W	1TJ1283-1A	71.3	33.8	474.4	.0067	71.0	-[c]	1/2 W
	-2B	79.5	44.0	553.0	.0067	82.7	84.8	1/2 W
	-7B	81.9	38.7	472.3	.0063	75.2	-[c]	1/2 W

a - G = gage section one inch from tabs, 1/2 W = between tab end and 1/2 width from tab end

b - Failure strain undefined

c - Specimen failed at less than 70 ksi, E_{s70} could not be determined

TABLE 39a

FULLY SUPPORTED COMPRESSION TEST DATA FOR DRY AND WET LAMINATE L2, TRANSVERSE - AS/3501-5A

Temp. °F	Specimen ID	Average Area (in.^{2})	Ultimate Load P_{ult}, kip	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Secant Modulus at 17 ksi E_{s17}, psi x 10^6	Failure[a] Location
72D	1TJ1245-2A	.1256	5.3	42.4	.0170	2.5	2.7	W
	1TJ1283-1B	.1288	5.7	44.6	.0187	2.4	2.7	G
	-4E	.1249	5.5	44.3	.0188	2.4	2.8	G
275W	1TJ1283-17D	.1264	3.4	26.7	.0180	1.5	1.9	G
	-5E	.1252	3.3	26.2	.0177	1.5	1.8	G
	-8E	.1250	3.2	25.8	.0170	1.5	1.8	G

a - G - gage section one inch from tabs

TABLE 39b

FULLY SUPPORTED COMPRESSION TEST DATA FOR DRY AND WET LAMINATE L2 TRANSVERSE - AS/3501-5A

Temp. ^oC	Specimen ID	Average Area mm^2	Ultimate Load P_{ult}, kN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus at 117 MPa E_{s117} GPa	Failure Location[a]
22D	1TJ1245-2A	81.0	23.6	292.4	.0170	17.2	18.6	W
	1TJ1283-1B	83.1	25.4	307.5	.0187	16.6	18.6	G
	-4E	80.6	24.5	305.4	.0188	16.0	19.3	G
135W	1TJ1283-17D	81.5	15.1	184.1	.0180	10.3	13.1	G
	-5E	80.8	14.7	180.6	.0177	10.3	12.4	G
	-8E	80.6	14.2	177.9	.0170	10.3	12.4	G

a - G = gage section one inch from tabs

TABLE 40a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY AND WET LAMINATE U1 - AS/3501-5A

	Specimen ID	Temperature °F	Average Area in.^{2}	Ultimate Load P_{ult}, kip	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Secant[a] Modulus E_s, psi x 10^6	Failure[b] Location
U1-L 0° Unidirectional	2TJ1281-13A	72D	0.0802	14.80	184.5	0.0119	15.6	17.7	G
	2TJ1281-15A	72D	0.0812	12.40	152.7	0.0092	16.7	17.9	G
	2TY1281-4EB	72D	0.0811	10.52	129.7	0.0075	17.3	18.7	1/2 W
	2TJ1281-19B	72W	0.0847	8.68	102.5	0.0061	16.9	17.7	1/2 W
	2TJ1281-22B	72W	0.0832	8.14	97.8	-[c]	-[c]	17.7	1/2 W
	2TY1281-24B	72W	0.0798	7.14	89.5	0.0042	21.2	20.3	G
	2TJ1281-5A	275W	0.0806	6.12	75.9	0.0046	16.6	16.6	G
	2TY1281-6A	275W	0.0814	5.20	63.9	0.0038	17.0	-	1/2 W
	2TJ1281-2EB	275W	0.0821	5.18	63.1	0.0036	17.5	-	G
U1-T 90° Unidirectional	2TJ1281-12C	72D	0.0821	2.83	34.5	010984	- d	- d	G
	2TJ1281-16C	72D	0.0817	2.95	36.0	0.0986	- d	- d	1/2 W
	2TJ1281-18C	72D	0.0819	2.78	33.9	0.0936	- d	- d	G
	2TJ1281-15C	275W	0.0821	1.48	18.0	-	0.54	0.55	G
	2TJ1281-23C	275W	0.0821	1.16	14.2	0.0291	0.49	-	G
	2TJ1281-24C	275W	0.0821	1.19	14.5	0.0324	0.45	-	G

a - E_s at 70 ksi for U1-L; E_s at 17 ksi for U1-T

b - G - gage section one inch from tabs. 1/2 W = between tab end and 1/2 width from tab end.

c - Extensometer slipped - data not available

d - Only crosshead deflection was measured; strain determination inaccurate

TABLE 40b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR DRY AND WET LAMINATE U1 - AS/3501-5A

	Specimen ID	Temperature °C	Average Area mm^2	Ultimate Load P_{ult}, KN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm in 50.8mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus[a] E_s, GPa	Failure[b] Location
U1-L 0° Unidirectional	2TJ1281-13A	22D	51.7	65.8	1272	0.0119	108	122	G
	2TJ1281-15A	22D	52.4	55.2	1053	0.0092	115	124	G
	2TY1281-4EB	22D	52.3	46.8	894	0.0075	119	129	1/2 W
	2TJ1281-19B	22W	54.6	38.6	707	0.0061	116	122	1/2 W
	2TJ1281-22B	22W	53.7	36.2	674	-c	-c	122	1/2 W
	2TJ1281-24B	22W	51.5	31.8	617	0.0042	146	140	G
	2TJ1281-5A	135W	52.0	27.2	523	0.0046	114	114	G
	2TJ1281-6A	135W	52.5	23.1	440	0.0038	117	-	1/2 W
	2TJ1281-2EB	135W	53.0	23.0	435	0.0036	121	-	G
U1-T 90° Unidirectional	2TJ1281-12C	22D	53.0	12.6	238	0.0984	d	d	G
	2TJ1281-16C	22D	52.7	13.1	248	0.0986	d	d	1/2 W
	2TJ1281-18C	22D	52.8	12.4	234	0.0936	d	d	G
	2TJ1281-15C	135W	53.0	6.6	124	-	3.7	3.8	G
	2TJ1281-23C	135W	53.C	5.2	98	0.0291	3.4	-	G
	2TJ1281-24C	135W	53.0	5.3	100	0.0324	3.1	-	G

a - E_s at 70 ksi for U1-L; E_s at 17 ksi for U1-T

b - G = gage section one inch from tabs. 1/2 W = between tab end and 1/2 width from tab end.

c - Extensometer slipped - data not available

d - Only crosshead deflection was measured; strain determination inaccurate

4.7 Column Buckling Tests

The approach to the column compression strength investigation as well as the procedures and equipment used are described in Section 1, and the scope of the program is outlined in Section 2. Each of the 1700-odd tests resulted in an instability or failure load, defined by the peak value of the recorded load vs. test head deflection curve. The test results are listed in Tables 41 through 58. The test data are also plotted as column curves of failure stress vs. pin-end length in Section 5, where further interpretation is supported by an analytical approach.

To provide a means of assessing the effect of "hot, wet" environment on the column strength of the two materials, the averages of the test values obtained with the different laminates at 22°C, dry and at 135°C, wet, are tabulated in Tables 59 and 60. Also shown are the percentage reductions attributed to the hot, wet condition. In Table 61, the average test values of T300/5208 and AS/3501-5A specimens are compared side-by-side. Differences due to material, conditioning, and environment are slight or negligible at the longest column length, but become more and more important as the buckling length is reduced.

4.8 Effect of Drying and Effect of Reconditioning on Column Behavior

The baseline "dry" test data were obtained as noted previously on specimens which were stored under "laboratory normal" environmental conditions which were held near 22°C (72°F) and 40% RH until moisture sorption and distribution had reached a close approximation of equilibrium. To determine how much different the performance would be if the specimens were absolutely dry, column tests were conducted on a complete set of specimens which were first placed in a drying environment (93°C (200°F) in vacuo) until the residual moisture, as indicated by the asymptote of the weight loss vs. time plot, was less than 0.1 percent. Approximately four weeks were required for this drying operation.

A second set of specimens was subjected not only to the drying procedure, but to a subsequent moisture conditioning identical to that used for the baseline "wet" specimens. These specimens were identified as "reconditioned."

TABLE 41

COLUMN BUCKLING DATA FOR DRY LAMINATE L1, LONGITUDINAL - T300/5208

Specimen ID	Temperature °C	°F	Column Length mm	in.	Buckling MPa	ksi	Column Length mm	in.	Buckling MPa	ksi
2TY1218-29A	-54	-65	40.8	1.606	124.1	18.0	20.0	.789	385.5	52.0
2TY1218-31B					117.9	17.1			370.2	53.7
2TY1218-40A					115.1	16.7			362.7	52.6
2TY1218-24A	-54	-65	32.4	1.276	166.2	24.1	14.5	.571	463.3	67.2
1TY1224-15A					180.6	26.2			464.0	67.3
1TY1226-20A					-	-			484.0	70.2
1TY1226-25B					173.1	25.1			507.4	73.6
2TY1218-37A	-54	-65	26.9	1.058	246.1	35.7	8.8	.347	413.7	60.0
2TY1218-19B					-	-			509.5	73.9
1TY1224-8A					233.0	33.8			464.7	67.4
1TY1224-38B					235.8	34.2			428.8	62.2
2TY1218-16A	22	72	40.8	1.606	-	-	20.0	.789	354.4	51.4
1TY1224-17B					110.3	16.0			350.2	50.8
1TY1224-23B					106.2	15.4			324.0	47.0
1TY1224-26A [a]					109.6	15.9			345.4	50.1
1TY1224-41B					115.1	16.7			354.4	51.4
1TY1226-7A [b]					107.5	15.6			343.4	49.8
1TY1226-7A [b]					106.2	15.4			343.4	49.8
2TY1218-1G	22	72	32.4	1.276	163.4	23.7	14.5	.571	405.4	58.8
1TY1224-14A					171.7	24.9			- [c]	- [c]
1TY1226-3A					160.6	23.3			309.6	44.9
1TY1226-7A [b]					164.1	23.8			- [b]	- [b]
1TY1226-7A [b]					164.1	23.8			- [b]	- [b]
1TY1226-20B					166.8	24.2			418.5	60.7
2TY1218-32B	22	72	26.9	1.058	224.8	32.6	8.8	.347	441.3	64.0
1TY1224-26A [a]					226.1	32.8			- [a]	- [a]
1TY1224-39A					217.2	31.5			401.3	58.2
1TY1226-19A					228.2	33.1			365.4	53.0
2TY1218-6B	93	200	40.8	1.606	110.3	16.0	20.0	.789	326.8	47.4
1TY1226-36A					108.9	15.8			336.5	48.8
2TY1226-17B					110.3	16.0			359.2	52.1
2TY1218-31A	93	200	32.4	1.276	162.7	23.6	14.5	.571	400.6	58.1
1TY1224-24B					166.8	24.2			362.0	52.5
1TY1226-36B					166.8	24.2			386.1	56.0
2TY1218-14B	93	200	26.9	1.058	-	-	8.8	.347	439.2	63.7
1TY1224-26B					233.0	33.8			460.6	66.8
1TY1226-35A					219.2 [c]	31.8 [c]			- [c]	- [c]
2TY1218-1A	135	275	40.8	1.606	110.3	16.0	20.0	.789	348.9	50.6
1TY1226-1A					110.3	16.0			350.2	50.8
1TY1226-39B					107.6	15.6			332.3	48.2
1TY1224-1B	135	275	32.4	1.276	161.3	23.4	14.5	571	359.9	52.2
1TY1226-6B					162.0	23.5			363.4	52.7
1TY1226-23A					166.8	24.2			293.0	42.5
2TY1218-7A	135	275	26.9	1.058	221.3 [d]	32.1 [d]	8.8	.347	-	-
2TY1218-13A					-	-			386.1	56.0
2TY1218-2B					-	-			434.3	63.0
2TY1218-22B					222.7	32.3			395.8	57.4
2TY1218-27B					233.0 [d]	33.8 [d]			-	-

a - Specimen was tested at two elastic lengths, 1.606 in. (40.8 mm) and 1.058 in. (26.9 mm) before testing to failure at a column length of 0.789 in. (20.0 mm).

b - Specimen was tested four times in the elastic region before testing to failure at a column length of 0.789 in. (20.0 mm).

c - Specimen failed prematurely due to human error.

d - Specimen failed. Could not be tested at the shorter length.

TABLE 42

COLUMN BUCKLING DATA FOR WET LAMINATE L1, LONGITUDINAL - T300/5208

Specimen ID	Temperature °C	°F	Column Length mm	in.	σ Buckling MPa	ksi	Column Length mm	in.	σ Buckling MPa	ksi
2TY1218-39B	-54	-65	40.8	1.606	112.4	16.3	20.0	0.789	388.9	56.4
1TY1226-19B					108.9	15.8			374.4	54.3
1TY1226-27A					119.3	17.3			316.5	45.9
1TY1224-35A	-54	-65	32.4	1.276	177.2	25.7	14.5	0.571	441.9	64.1
1TY1224-39B					176.5	25.6[b]			-	-
1TY1226-37B					178.6	25.9			486.1	70.5
2TY1218-4B	-54	-65	26.9	1.058	245.5	35.6	8.8	0.347	581.2	84.3
2TY1218-26A					236.5	34.3			478.5	69.4
1TY1224-30B					235.1	34.1			457.1	66.3
1TY1224-10A	22	72	40.8	1.606	115.1	16.7	20.0	0.789	366.8	53.2
1TY1226-8B					106.2	15.4			350.3	50.8
1TY1226-23B					111.7	16.2			368.9	53.5
2TY1218-22A	22	72	32.4	1.276	162.0	23.5	14.5	0.571	457.1	66.3
2TY1218-24B					175.1	25.4			507.4	73.6
1TY1226-1B					168.9	24.5			350.1	51.5
2TY1218-2A	22	72	26.9	1.058	233.0	33.8	8.8	0.347	466.8	67.7
1TY1226-27B					237.2	34.4			424.7	61.6
1TY1226-38B					238.6	34.6			393.7	57.1
2TY1218-4G	93	200	40.8	1.606	109.6	15.9	20.0	0.789	286.8	41.6
2TY1218-41A					108.9	15.8			322.0	46.7
1TY1226-33B					104.8	15.2			276.5	40.1
2TY1218-11A	93	200	32.4	1.276	158.6	23.0	14.5	0.571	384.0	55.7
1TY1224-1G					164.8	23.9			457.8	66.4
1TY1226-21A					166.2	24.1			402.0	58.3
2TY1218-38A	93	200	26.9	1.058	226.9	32.9	8.8	0.347	400.6	58.1
2TY1218-39A					227.5	33.0			323.4	46.9
1TY1226-33A					218.6	31.7[a]			-	-
2TY1218-4A	135	275	40.8	1.606	108.9	15.8	20.0	0.789	326.1	47.3
2TY1218-28B					106.9	15.5			304.7	44.2
1TY1224-26					106.2	15.4			295.8	42.9
1TY1224-28A	135	275	32.4	1.276	159.3	23.1	14.5	0.571	374.5	50.4
1TY1226-2A					157.2	22.8			297.2	43.1
1TY1226-2G					160.0	23.2			267.5	38.8
2TY1218-5A	135	275	26.9	1.058		-	8.8	0.347	361.3	52.4
1TY1224-18B					234.4	34.0			410.2	59.5
1TY1224-34B						-			310.3	45.0
1TY1226-15A					234.4	34.0[a]			-	-
1TY1226-34A	135	275	40.8	1.606	106	15.3				
1TY1226-32B			32.4	1.276	153	22.2				
2TY1218-13B			26.9	1.058	216	31.4				
2TY1218-29B	135	275	20.0	0.789	326	47.3				
1TY1226-1A			20.0	0.789	279	40.5				
1TY1226-17A			20.0	0.789	296	42.9				
1TY1226-34A			20.0	0.789	302	43.8				
1TY1226-41A			20.0	0.789	310	45.0				
1TY1224-34A	135	275	14.5	0.571	345	50.0				
1TY1224-6B			14.5	0.571	454	56.8				
1TY1224-9B			14.5	0.571	336	48.8				
1TY1224-21B			14.5	0.571	341	49.5				
1TY1226-39A			14.5	0.571	298	43.2				
2TY1218-34B	135	275	8.8	0.347	363	52.6				
1TY1226-10A			8.8	0.347	370	53.6				
1TY1226-21A			8.8	0.347	351	50.9				
1TY1226-25A			8.8	0.347	354	51.3				
1TY1226-3B			8.8	0.347	368	53.4				

a - Specimen failed; could not be tested at shorter length

TABLE 43

COLUMN BUCKLING DATA FOR DRY LAMINATE L1, TRANSVERSE - T300/5208

SPECIMEN ID	Temperature °C	°F	Column Length mm	in.	Buckling MPa	ksi	Column Length mm	in.	Buckling MPa	ksi
1TY1224-10F	-54	-65	40.8	1.606	93.1	13.5	20.0	.789	311.6	45.2
1TY1226-3C					91.0	13.2			306.1	44.4
1TY1226-8C					88.9	12.9			307.5	44.6
2TY1218-8E	-54	-65	32.4	1.276	137.9	20.0	14.5	.571	437.1	63.4
1TY1224-12E					138.6	20.1			475.0	68.9
1TY1226-10F					138.6	20.1			376.4	54.6
2T1218-6C	-54	-65	26.9	1.058	188.9	27.4	8.8	.347	332.3	48.2
2TY1218-12C					187.5	27.2			416.4	60.4
1TY1224-19D					190.3	27.6			475.7	69.0
1TY1224-4F	22	72	40.8	1.606	86.2	12.5	20.0	.789	296.5	43.0
1TY1224-11F					86.2	12.5			291.6	42.3
1TY1226-4C					86.[illegible]	12.6			266.1	38.6
1TY1218-4C	22	72	32.4	1.276	[illegible].9	18.4	14.5	.571	355.1	51.5
1TY1224-10C					[illegible]	18.8			364.7	52.9
1TY1226-17E					131.0	19.0			396.4	57.5
1TY1224-2C	22	72	26.9	1.058	186.2	27.0	8.8	.347	392.3	56.9
1TY1224-14D					178.6	25.9			415.1	60.2
1TY1226-12C					177.9	25.8			352.3	51.1
1TY1226-19C					179.3[a]	26.0[a]			-	-
2TY1218-5F	93	200	40.8	1.606	89.6	13.0	20.0	.789	290.3	42.1
1TY1224-5D					88.9	12.9			306.1	44.4
1TY1226-8D					86.9	12.6			274.4	39.8
2TY1218-6D	93	200	32.4	1.276	165.5	24.0	14.5	.571	396.4	57.5
2TY1218-16D					135.1	19.6			373.7	54.2
1TY1224-2F					128.2	18.6			368.2	53.4
2TY1218-2C	93	200	26.9	1.058	184.1	26.7	8.8	.347	375.8	54.5
1TY1224-11D					184.8	26.8			370.2	53.7
1TY1224-12F					182.0	26.4			424.7	61.6
2TY1218-9C	135	275	40.8	1.606	88.2	12.8	20.0	.789	283.4	41.1
1TY1224-7D					88.2	12.8			290.3	42.1
1TY1224-18D					87.6	12.7			283.4	41.1
2TY1218-11F	135	275	32.4	1.273	131.7	19.1	14.5	.571	342.7	49.7
1TY1224-9E					144.8	21.0			325.4	47.2
1TY1226-10E					130.3	18.9			301.3[b]	43.7[b]
1TY1226-14F					128.9	18.7			-	-
1TY1224-1E	135	275	26.9	1.058	171.0	24.8	8.8	.347	348.9	50.6
1TY1224-2E					184.1	26.7			353.0	51.2
1TY1224-16E					183.4	26.6			350.9	50.9

a - Specimen failed. Could not be tested at the shorter length.

b - Specimen failed prematurely due to human error.

TABLE 44

COLUMN BUCKLING DATA FOR WET LAMINATE L1, TRANSVERSE - T300/5208

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi
1TY1224-1D	-54	-65	40.8	1.606	87.6	12.7	20.0	0.789	301.3	43.7
1TY1224-17E					81.4	11.8			328.9	47.7
1TY1224-8F					86.2	12.5			315.1	45.7
2TY1218-3E	-54	-65	32.4	1.276	135.8	19.7	14.5	0.571	399.9	58.0
1TY1224-8D					146.2	21.2			395.8	57.4
1TY1226-13F					143.4	20.8			406.1	58.9
2TY1218-10F	-54	-65	26.9	1.058	186.2	27.0	8.8	0.347	449.5	65.2
1TY1226-2C					195.1	28.3			367.5	53.3
1TY1226-17D					190.9	27.7			410.9	59.6
1TY1226-6F	22	72	40.8	1.606	86.9	12.6	20.0	0.789	302.0	43.8
1TY1226-8F					86.2	12.5			284.8	41.3
1TY1226-15E					85.5	12.4			304.7	44.2
2TY1218-9D	22	72	32.4	1.276	131.0	19.0	14.5	0.571	368.9	53.5
2TY1218-12D					133.1	19.3			370.2	53.7
2TY1218-14F					131.0	19.0			380.6	55.2
2TY1218-15D	22	72	26.9	1.058	186.2	27.0	8.8	0.347	424.0	61.5
1TY1226-1C					172.4	25.0			357.8	51.9
1TY1226-4E					182.7	26.5			363.4	52.7
2TY1218-1E	93	200	40.8	1.606	71.7	10.4	20.0	0.789	246.1	35.7
2TY1218-7F					84.8	12.3			274.4	39.8
1TY1224-7E					86.9	12.6			279.9	40.6
2TY1218-8C	93	200	32.4	1.276	129.6	18.8	14.5	0.571	306.8	44.5
1TY1224-1F					117.2	17.0			345.4	50.1
1TY1226-18D					126.2	18.3			343.4	49.8
1TY1224-15F	93	200	26.9	1.058	195.1	28.3	8.8	0.347	362.7	52.6
1TY1226-13E					188.2	27.3			374.5	50.4
1TY1226-14E					188.9	27.4			374.5	50.4
2TY1218-1C	135	275	40.8	1.606	75.2	10.9	20.0	0.789	256.5	37.2
1TY1224-5F					85.5	12.4[b]			276.5	40.4
1TY1224-16D					94.5	13.7			-	-
1TY1224-17D					88.9	12.9			286.1	41.5
2TY1218-5C	135	275	32.4	1.276	129.6	18.8	14.5	0.571	259.2	37.6
1TY1224-13D					135.1	19.6			350.3	50.8
1TY1226-15C					126.9	18.4			271.7	39.4
2TY1218-14E	135	275	26.9	1.058	180.6	26.2	8.8	0.347	309.6	44.9
1TY1224-16D						-			346.8	50.3
1TY1224-16F					187.5	27.2			357.1	51.8
1TY1226-9E						26.7			a	a
1TY1224-10E	135	275	40.8	1.606	92	13.3				
1TY1224-14C			32.4	1.276	119	17.3				
1TY1224-3C			26.9	1.058	174	25.3				
2TY1218-10C	135	275	20.0	0.789	270	39.1				
2TY1218-19E			20.0	0.789	258	37.4				
1TY1224-18C			20.0	0.789	270	39.1				
1TY1224-10E			20.0	0.789	286	41.5				
1TY1226-7D			20.0	0.789	240	34.8				
2TY1218-4D	135	275	14.5	0.571	295	42.8				
2TY1218-13D			14.5	0.571	306	44.4				
2TY1218-16E			14.5	0.571	284	41.2				
1TY1224-4C			14.5	0.571	307	44.5				
1TY1224-13C			14.5	0.571	336	48.7				
1TY1224-14C			14.5	0.571	339	49.2				
2TY1218-13C	135	275	8.8	0.347	318	46.1				
2TY1218-16C			8.8	0.347	321	46.5				
1TY1224-3C			8.8	0.347	270	39.2				
1TY1226-15D			8.8	0.347	308	44.6				
1TY1226-16E			8.8	0.347	290	42.0				

a - Invalid due to operator error.

b - Specimen failed. Could not be tested at the shorter length

TABLE 45

COLUMN BUCKLING DATA FOR DRY LAMINATE L2, LONGITUDINAL - T300/5208

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	Buckling MPa	Buckling ksi	Column Length mm	Column Length in.	Buckling MPa	Buckling ksi
1TY1225-30A	-54	-65	40.8	1.606	353.0	51.2	20.0	.789	788.8	114.4
2TY1225-16A					344.0	49.9			832.2	120.7
2TY1225-23B					354.4	51.4			889.4	129.0
1TY1225-23B	-54	-65	32.4	1.276	527.4	76.5	14.5	.571	936.3	135.8
2TY1225-22B					503.3	73.0			998.4	144.8
2TY1226-38B					514.3	74.6			986.0	143.0
2TY1226-11A	-54	-65	26.9	1.058	656.4	95.2	8.8	.347	946.0	137.2
2TY1226-11B					648.1	94.0			1070.1	155.2
2TY1226-29A					637.1[a]	92.4[a]			-	-
2TY1225-6A	22	72	40.8	1.606	334.4	48.5	20.0	.789	700.5	101.6
2TY1226-1B					315.1	45.7			777.0	112.7
2TY1226-15A					335.8	48.7			729.5	105.8
1TY1225-2A	22	72	32.4	1.276	498.5	72.3	14.5	.571	861.2	124.9
1TY1225-20B					509.5	73.9			808.8	117.3
2TY1226-39B					504.0	73.1			850.8	123.4
1TY1225-2B	22	72	26.9	1.058	656.4[a]	95.2[a]	8.8	.347	-	-
1TY1225-34B					650.2	94.3			1044.6	151.5
2TY1225-17A					635.0	92.1			1010.1	146.5
2TY1226-19A					-	-			939.8	136.3
2TY1225-8A	93	200	40.8	1.606	339.2	49.2	20.0	.789	710.8	103.1
2TY1226-22B					344.7	50.0			721.2	104.6
2TY1226-37A					335.8	48.7			748.8	108.6
1TY1225-30B	93	200	32.4	1.273	501.2	72.7	14.5	.571	858.4	124.5
2TY1226-10A					492.3 [a]	71.4 [a]			-	-
2TY1226-38A					470.9 [a]	68.3 [a]			-	-
1TY1225-33B	93	200	26.9	1.058	-	-	8.8	.347	878.4	127.4
2TY1226-18A					620.5 [a]	90.0 [a]			-	-
2TY1226-22A					-	-			858.4	124.5
1TY1225-17A	135	275	40.8	1.606	338.5 [a]	49.1 [a]	20.0	.789	-	-
1TY1225-33A					344.7	50.0			694.3 [b]	100.7 [b]
2TY1226-21B					333.7	48.4			-	-
1TY1225-23A	135	275	32.4	1.276	484.0	70.2	14.5	.571	695.0	100.8
2TY1225-34A					495.7	71.9			683.3	99.1
2TY1226-21A					477.1 [a]	69.2 [a]			-	-
2TY1226-28A					478.5 [a]	69.4 [a]			-	-
1TY1225-13B	135	275	26.9	1.058	-	-	8.8	.347	827.4	120.0
2TY1225-4A					619.8 [a]	89.9 [a]			-	-
2TY1225-7B					650.9 [a]	94.4 [a]			-	-
2TY1225-9A					-	-			917.7	133.1
2TY1225-39A					508.1 [a]	73.7 [a]			-	-
2TY1226-25A					-	-			823.9	119.5

a - Specimen failed. Could not be tested at the shorter length.

b - Sprcimen failed prematurely due to human error.

TABLE 46

COLUMN BUCKLING DATA FOR WET LAMINATE L2, LONGITUDINAL - T300/5208

Specimen ID	Temperature °C	°F	Column Length mm	in.	σ Buckling MPa	ksi	Column Length mm	in.	σ Buckling MPa	ksi
2TY1225-32A	-54	-65	40.8	1.606	345.4	50.1	20.0	0.789	760.5	110.3
2TY1226-5B					360.6	52.3			896.3	130.0
2TY1226-9A					354.4	51.4			832.9	120.8
1TY1225-1B	-54	-65	32.4	1.276	494.4	71.7	14.5	0.571	861.2	124.9
2TY1226-30A					511.6	74.2[a]			-	-
2TY1226-39A					504.0	73.1			823.9	119.5
1TY1225-5A	-54	-65	26.9	1.058	643.3	93.3	8.8	0.347	939.8	136.3
2TY1226-32A					620.5	90.0[a]			-	-
2TY1226-36B					685.3	99.4			896.3	130.0
1TY1225-14B	22	72	40.8	1.606	354.4	51.4	20.0	0.789	846.0	122.7
1TY1225-18A					344.0	49.9			792.2	114.9
2TY1226-8A					344.0	49.9			837.0	121.4
1TY1225-21B	22	72	32.4	1.276	494.4	71.7	14.5	0.571	817.7	118.6
2TY1225-11A					486.1	70.5[a]			-	-
2TY1226-25B					497.8	72.2			863.2	125.2
2TY1225-31B	22	72	26.9	1.058	645.3	93.6[a]	8.8	0.347	-	-
2TY1226-2G						-			777.7	112.8
2TY1226 G3A					648.1	94.0[a]				-
1TY1225-41A	93	200	40.8	1.606	333.0	48.3	20.0	0.789	697.1	101.1
2TY1225-32B					330.3	47.9[b]			-	-
2TY1226-27A					343.4	49.8			743.3	107.8
1TY1225-19B	93	200	32.4	1.276	426.8	61.9	14.5	0.571	749.5	108.7
2TY1225-12A					470.9	68.3			619.1	89.8
2TY1225-31A					-	-			534.3	77.5
2TY1226-24A					474.4	68.8[a]			-	-
1TY1225-22B	93	200	26.9	1.058	617.1	89.5[a]	8.8	0.347	-	-
2TY1225-16B						-			797.7	115.7
2TY1225-21A					574.4	79.4			679.8	98.6
2TY1225-36A						-			589.5	85.5
2TY1225-15A	135	275	40.8	1.606	333.7	48.4	20.0	0.789	722.6	104.8
2TY1226-19B					330.9	48.0			708.1	102.7
1TY1225-25B	135	275	32.4	1.276	464.0	67.3	14.5	0.571	693.6	100.6
1TY1225-39A						-			600.5	87.1
2TY1225-11B					466.1	67.6[a]			-	-
2TY1226-23A					473.0	68 6[a]			-	-
2TY1225-8B	135	275	26.9	1.058	589.5	86.5	8.8	0.347	-	-
2TY1225-2G					526.1	76.3			630.9	91.5
2TY1226-18B						-			590.9	85.7
2TY1226-29B					536.4	77.8			761.9	110.5
2TY1226-4B	135	275	40.8	1.606	333	48.3				
2TY1226-12B	135	275	32.4	1.276	426	61.8				
2TY1225-25A	135	275	26.9	1.058	545	79.0				
1TY1225-6B	135	275	20.0	0.789	652	94.5				
2TY1226-12A			20.0	0.789	660	95.7				
2TY1226-33A			20.0	0.789	701	101.7				
2TY1226-4B			20.0	0.789	625	90.6				
2TY1226-20B			20.0	0.789	758	109.9				
2TY1226-41B			20.0	0.789	667	96.8				
1TY1225-24A	135	275	14.5	0.571	671	97.3				
1TY1225-27B			14.5	0.571	645	93.5				
2TY1225-2A			14.5	0.571	576	83.6				
2TY1226-16A			14.5	0.571	652	94.5				
2TY1226-12B			14.5	0.571	610	88.5				
2TY1226-30B			14.5	0.571	686	99.5				
1TY1225-9B	135	275	8.8	0.347	678	98.3				
1TY1225-11B			8.8	0.347	658	95.5				
2TY1225-5A			8.8	0.347	533	77.3				
2TY1225-25A			8.8	0.347	647	93.8				
2TY1225-28A			8.8	0.347	664	96.3				
2TY1226-13B			8.6	0.347	681	98.8				

a - Specimen failed. Could not be tested at the shorter length.

TABLE 47

COLUMN BUCKLING DATA FOR DRY LAMINATE L2, TRANSVERSE - T300/5208

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	Buckling MPa	Buckling ksi	Column Length mm	Column Length in.	Buckling MPa	Buckling ksi
1TY1225-1C	54	-65	40.8	1.606	84.8	12.3	20.0	.789	217.9	31.6
2TY1225-1E					87.6	12.7			177.2	25.7
2TY1226-18C					84.1	12.2			225.4	32.7
1TY1225-10E	54	-65	32.4	1.276	125.5	18.2	14.5	.571	223.4	32.4
2TY1225-16C					126.9	18.4			224.1	32.5
2TY1225-3D					127.6	18.5			237.9	34.5
1TY1225-3C	54	-65	26.9	1.058	176.5[a]	25.6[a]	8.8	.347	-	-
2TY1225-17F					167.5	24.3			223.4	32.4
2TY1226-5C					166.2	24.1			233.0	33.8
1TY1225-11F	22	72	40.8	1.606	76.5	11.1	20.0	.789	188.9	27.4
2TY1225-7C					75.8	11.0			168.2	24.4
2TY1226-10F					77.9	11.3			213.7	31.0
1TY1225-19[d]	22	72	32.4	1.276	119.3	17.3	14.5	.571	210.3	30.5
2TY1225-19[c]					116.5	16.9			200.0	29.0
2TY1226-15E					119.3	17.3			204.1	29.6
2TY1225-7D	22	72	26.9	1.058	164.1[a]	23.8[a]	8.8	.347	-	-
2TY1226-3F					-	-			222.7	32.3
2TY1226-6E					-	-			226.2	32.8
2TY1226-10C					158.6[a]	23.0[a]			-	-
2TY1226-14C					-	-			204.8	29.7
1TY1225-15D	93	200	40.8	1.606	75.8	11.0	20.0	.789	182.0	26.4
1TY1225-17C					78.6	11.4			166.2	24.1
2TY1226-7C					73.8	10.7			190.3	27.6
1TY1225-4E	93	200	32.4	1.276	114.4	16.6	14.5	.571	184.8	26.8
2TY1225-18D					113.1	16.4			184.8	26.8
2TY1226-4C					109.6	15.9			186.8	27.1
2TY1226-3D	93	200	26.9	1.058	-	-	8.8	.347	186.8	27.1
2TY1226-4D					-	-			189.6	27.5
2TY1226-19D					155.8[a]	22.6[a]			-	-
1TY1225-5D	135	275	40.8	1.606	74.5	10.8	20.0	.789	180.6	26.2
2TY1225-2C					69.6	10.1			184.1	26.7
2TY1225-8C					75.8	11.0			154.4	22.4
1TY1225-16C	135	275	32.4	1.276	113.1	16.4	14.5	.571	182.7	26.5
2TY1225-1D					111.7	16.2			183.4	26.6
2TY1225-9E					119.3[a]	17.3[a]			-	-
2TY1226-6F					114.4	16.6			182.7	26.5
1TY1225-7C	135	275	26.9	1.058	-	-	8.8	.347	180.6	26.2
1TY1225-8E					160.0[a]	23.2[a]			-	-
1TY1225-11C					154.4[a]	22.4[a]			-	-
2TY1226-11D					-	-			178.6	25.9

a - Specimen failed. Could not be tested at the shorter length.

TABLE 48

COLUMN BUCKLING DATA FOR WET LAMINATE L2, TRANSVERSE - T300/5208

Specimen ID	Temperature °C	°F	Column Length mm	in.	σ Buckling MPa	ksi	Column Length mm	in.	σ Buckling MPa	ksi
1TY1225-8D	-54	-65	40.8	1.606	91.7	13.3	20.0	0.789	240.6	34.9
2TY1225-1F					82.7	12.0			230.3	33.4
2TY1226-13C					83.4	12.1			237.9	34.5
1TY1225-15F	-54	-65	32.4	1.276	134.4	19.5	14.5	0.571	219.9	31.9
2TY1225-16E					128.2	18.6			242.0	35.1
2TY1226-6D					127.6	18.5			199.3	28.9
2TY1225-16D	-54	-65	26.9	1.058	186.8	27.1	8.8	0.347	239.2	34.7
2TY126-17D					184.8	26.8[a]			-	-
2TY1226-1F					176.5	25.6			248.2	36.0
1TY1225-2C	22	72	40.8	1.606	78.6	11.4	20.0	0.789	210.3	30.5
1TY1225-15C					80.0	11.6			202.7	29.4
2TY1226-9C					79.3	11.5			219.9	31.9
1TY1225-9D	22	72	32.4	1.276	122.0	17.7	14.5	0.571	220.6	32.0
2TY1225-9F					122.3	17.8			214.4	30.8
2TY1225-10F					121.3	17.6			219.9	31.9
1TY1225-17E	22	72	26.9	1.058	162.0	23.5[a]	8.8	0.347	-	-
2TY1225-3E						-			206.2	29.9
2TY1225-11E					165.5	24.0[a]			-	-
2TY1225-11C	93	200	40.8	1.607	75.8	11.0	20.0	0.789	181.3	26.3
2TY1226-11E					78.6	11.4			189.6	27.5
2TY1226-14E					74.5	10.8			195.1	28.3
1TY1225-18C	93	200	32.4	1.276	108.9	15.8	14.5	0.571	175.8	25.5
2TY1226-9F					110.3	16.0			193.1	28.0
2TY1226-17F					115.8	16.8			194.4	28.2
1TY1225-9C	93	200	26.9	1.058	148.9	21.6[a]	8.8	0.347	-	-
2TY1225-12F					159.3	23.1[a]			-	-
2TY1226-3C					144.8	21.0			201.3	29.2
1TY1225-12F	135	275	40.8	1.606	75.8	11.0	20.0	0.789	171.0	24.8
1TY1225-13F					75.8	11.0			165.5	24.0
2TY1-25-5C					70.3	10.2			162.0	23.5
1TY1225-10F	135	275	32.4	1.276	107.6	15.6	14.5	0.571	177.2	25.7
1TY1225-11D					106.9	15.5			166.2	24.1
2TY1226-16C					100.0	14.5			168.2	24.4
1T1225-5F	135	275	26.9	1.058	146.9	20.3[a]	8.8	0.347	-	-
2TY1225-4C					142.0	20.6			193.7	28.1
2TY1226-17E					146.9	21.3			187.5	27.2
2TY1226-8F	135	275	40.8	1.606	71	10.3				
1TY1225-4C	135	275	32.4	1.276	106	15.4				
2TY1225-18E	135	275	26.9	1.058	143	20.7				
1TY1225-9F	135	275	20.0	0.789	142	20.6				
2TY1225-12E			20.0	0.789	156	22.6				
2TY1226-4E			20.0	0.789	155	22.5				
2TY1226-16E			20.0	0.789	160	23.2				
2TY1226-8F			20.0	0.789	154	22.4				
2TY1226-18F			20.0	0.789	159	23.0				
1TY1225-14D	135	275	14.5	0.571	159	23.0				
1TY1225-6E			14.5	0.571	160	23.2				
1TY1225-2F			14.5	0.571	168	24.4				
2TY1225-8E			14.5	0.571	167	24.2				
2TY1226-17C			14.5	0.571	163	23.6				
1TY1225-16E	135	275	8.8	0.347	172	25.0				
1TY1225-7F			8.8	0.347	166	24.1				
1TY1225-12D			8.8	0.347	177	25.6				
2TY1225-9C			8.8	0.347	166	24.1				
2TY1225-13D			8.8	0.347	165	23.9				

a - Specimen failed. Could not be tested at the shorter length.

TABLE 49

COLUMN BUCKLING DATA FOR DRY LAMINATE U1, LONGITUDINAL - T300/5208

	Temperature		Column Length		σ Buckling		Column Length		σ Buckling	
Specimen ID	°C	°F	mm	in.	MPa	ksi	mm	in.	MPa	ksi
1TY1216-24B	-54	-65	40.8	1.606	224.8	32.6	20.0	0.789	761.2	110.4
2TY1216-17A					235.8	34.2			743.2	107.8
1TY1218-26B					233.0	33.8			750.9	108.9
1TY1216-34B	-54	-65	32.4	1.276	348.2	50.5	14.5	0.571	954.2	138.4
1TY1218-5A					349.6	50.7			924.6	134.1
1TY1218-28B					345.4	50.1			a	a
1TY1216-22B	-54	-65	26.9	1.058	493.0	71.5	8.8	0.347	861.8	125.0
2TY1216-36B					478.5	69.4			1159.7	168.2
1TY1218-17B					481.9	69.9			1284.5	186.3
2TY1216-26B	22	72	40.8	1.606	223.4	32.4	20.0	0.789	737.0	106.9
1TY1218-18A					219.9	31.9			720.5	104.5
1TY1218-23B					219.2	31.8			716.4	103.9
1TY1218-9A	22	72	32.4	1.276	332.3	48.2	14.5	0.571	1010.1	146.5
1TY1218-21A					325.4	47.2			935.6	135.7
1TY1218-33A					337.2	48.9			832.9	120.8
1TY1216-18A	22	72	26.9	1.058	469.5	68.1[b]	-	-	-	-
1TY1216-37A					466.8	67.7	8.8	0.347	950.1	137.8
2TY1216-3A			-	-	-	-			963.9	139.8
2TY1216-19A			-	-	-	-			1080.4	156.7
2TY1216-9B					460.6	66.8			791.5	114.8[c]
1TY1218-24A			-	-	-	-			917.7	133.1
1TY1218-3B					474.4	68.8			1087.3	157.7
1TY1216-6A	93	200	40.8	1.606	224.8	32.6	20.0	0.789	713.6	103.5
1TY1216-1B					220.6	32.0			668.8	97.0
1TY1216-37B					228.9	33.2			765.3	111.0
1TY1216-31B	93	200	32.4	1.276	336.5	48.8	14.5	0.571	925.0	134.3
2TY1216-40A					320.6	46.5			941.1	136.5
1TY1218-4B					337.2	48.9			1023.9	148.5
1TY1216-29B	93	200	26.9	1.058	475.0	68.9	8.8	0.347	966.6	140.2
2TY1216-25A					446.1	64.7			875.6	127.0
2TY1216-12B					460.6	66.8			865.3	125.5
1TY1216-17A	135	275	40.8	1.606	233.7	33.9	20.0	0.789	720.5	104.5
1TY1216-30B					221.3	32.1			648.1	94.0
1TY1218-35B					224.8	32.6			695.0	100.8
2TY1216-15A	135	275	32.4	1.276	344.0	49.9	14.5	0.571	934.9	135.6
2TY1216-39B					341.3	49.5			918.4	133.2
1TY1218-27B					348.9	50.6			820.5	119.0
1TY1216-22A	135	275	26.9	1.058	477.8	69.3	8.8	0.347	938.4	136.1
2TY1216-34A					481.2	69.8			921.1	133.6
1TY1218-15B					464.0	67.3			828.1	120.1

a - Invalid due to operator error.

b - Specimen failed - could not be tested at the shorter length

c - Specimen delaminated - did not fracture into two pieces.

TABLE 50

COLUMN BUCKLING DATA FOR WET LAMINATE U1, LONGITUDINAL - T300/5208

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi
2TY1216-38A	22	72	40.79	1.606	232	33.6	20.04	0.789	716	103.8
2TY1216-25B			40.79	1.606	224	32.5	20.04	0.789	598	86.7
2TY1216-33B			40.79	1.606	226	32.8	20.04	0.789	727	105.4
2TY1216-26A			32.41	1.276	340	49.3	14.50	0.571	575	83.4
2TY1216-33A			32.41	1.276	295	42.8	14.50	0.571	927	134.5
2TY1216-29B			32.41	1.276	340	49.3	14.50	0.571	991	143.8
1TY1216-20A			26.87	1.058	455	66.0	8.81	0.347	873	126.6
2TY1216-30A			26.87	1.058	676	69.1	8.81	0.347	916	132.8
2TY1216-24B			26.87	1.058	450	65.3	8.81	0.347	1102	159.9
1TY1216-35A	135	275	40.79	1.606	211	30.6	20.04	0.789	498	72.3
1TY1216-9B			40.79	1.606	219	31.8	20.04	0.789	502	72.8
1TY1218-39A			40.79	1.606	219	31.7	20.04	0.789	616	89.3
2TY1216-22B			32.41	1.276	315	45.7	14.50	0.571	559	81.1
2TY1216-27B			32.41	1.276	301	43.7	14.50	0.571	481	69.8
2TY1216-34B			32.41	1.276	315	45.7	14.50	0.571	639	92.7
2TY1216-20B			-	-	-	-	8.81	0.347	820	118.0
2TY1216-28B			-	-	-	-	8.81	0.347	601	87.1
1TY1218-7B			26.87	1.058	420	60.9	-	-	-	-
1TY1216-15B			40.8	1.606	230	33.3				
1TY1218-36B			32.4	1.276	306	44.4				
2TY1216-39A			26.9	1.058	410	59.5				
1TY1216-2B			20.0	0.789	452	65.5				
1TY1216-7B			20.0	0.789	604	87.6				
2TY1216-18B			20.0	0.789	549	79.6				
2TY1216-19B			20.0	0.789	386	56.0				
1TY1218-20A			20.0	0.789	578	83.8				
1TY1216-31A			14.5	0.571	572	82.9				
1TY1216-32A			14.5	0.571	592	85.8				
1TY1216-6B			14.5	0.571	651	94.4				
1TY1216-20B			14.5	0.571	565	82.0				
1TY1216-36B			14.5	0.571	612	88.7				
2TY1216-20A			8.8	0.347	673	97.6				
2TY1216-27A			8.8	0.347	780	113.1				
2TY1216-37A			8.8	0.347	700	101.5				
2TY1216-35A			8.8	0.347	419	60.7				
2TY1216-37A			8.8	0.347	672	97.5				

TABLE 51

COLUMN BUCKLING DATA FOR DRY, LAMINATE U1, TRANSVERSE - T300/5208

Specimen	Temperature °C	°F	Column Length mm	in.	σ Buckling MPa	ksi	Column Length mm	in.	σ Buckling MPa	ksi
1TY1216-1C	-54	-65	40.8	1.606	24.8	3.6	20.0	0.789	91.0	13.2
1TY1216-7F					25.5	3.7			88.2	12.8
2TY1216-6F					22.8	3.3			82.7	12.0
2TY1216-7C	-54	-65	32.4	1.276	34.5	5.0	14.5	0.571	151.7	22.0
1TY1218-13E					37.9	5.5			160.0	23.2
1TY1218-11F					34.5	5.0			151.0	21.9
1TY1216-15F	-54	-65	26.9	1.058	53.8	7.8	8.8	0.347	236.5	34.3
1TY1216-16F					53.1	7.7			266.1	38.6
1TY1218-16F					54.5	7.9			168.2	24.4
1TY1216-7D	22	72	40.8	1.606	20.0	2.9	20.0	0.789	77.9	11.3
1TY1216-14D					20.0	2.9			79.3	11.5
1TY1218-6C					22.1	3.2			75.2	10.9
1TY1218-12E	22	72	32.4	1.276	32.4	4.7	14.5	0.571	131.7	19.1
1TY1218-12F					30.3	4.4			133.1	19.3
1TY1218-14F					32.4	4.7			127.6	18.5
2TY1216-13D	22	72	26.9	1.058	49.0	7.1	8.8	0.347	192.4	27.9
1TY1218-17C					47.6	6.9			197.2	28.6
1TY1218-6E					44.8	6.5			219.2	31.8
1TY1216-17D	93	200	40.8	1.606	22.1	3.2	20.0	0.789	72.4	10.5
1TY1216-6F					17.2	2.5			71.7	10.4
1TY1218-17F					21.4	3.1			75.8	11.0
1TY1218-10C	93	200	32.4	1.276	28.3	4.1	14.5	0.571	110.3	16.0
1TY1218-5E					29.6	4.3			112.4	16.3
1TY1218-15F					31.7	4.6			116.5	16.9
1TY1218-9C	93	200	26.9	1.058	40.7	5.9	8.8	0.347	152.4	22.1
1TY1218-14C					44.1	6.4			115.8	16.8
1TY1218-2D					42.8	6.2			178.6	25.9
1TY1216-16E	135	275	40.8	1.606	8.3	1.2	20.0	0.789	74.5	10.8
2TY1216-14C					20.7	3.0			65.5	9.5
2TY1216-12E					20.0	2.9			70.3	10.2
1TY1216-11D	135	275	32.4	1.276	29.6	4.3	14.5	0.571	105.5	15.3
2TY1216-1D					30.3	4.4			100.7	14.6
1TY1218-7E					28.3	4.1			100.0	14.5
1TY1216-9C	135	275	26.9	1.058	44.8	6.5	8.8	0.347	125.5	18.2
1TY1216-3D					41.4	6.0			102.0	14.8
1TY1216-6D					41.4	6.0			121.3	17.6

TABLE 52

COLUMN BUCKLING DATA FOR WET, LAMINATE U1, TRANSVERSE - T300/5208

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi
1TY1216-15C	-54	-65	40.79	1.606	20	3.6	20.04	0.789	83	12.0
2TY1216-10C			40.79	1.606	20	2.9	20.04	0.789	83	12.0
2TY1216-16D			40.79	1.606	28	4.0	20.04	0.789	89	12.9
1TY1216-3E	-54	-65	32.41	1.276	33	4.8	14.50	0.571	145	21.1
1TY1218-1E			32.41	1.276	32	4.7	14.50	0.571	144	20.9
1TY1218-8F			32.41	1.276	36	5.2	14.50	0.571	159	23.1
1TY1216-10D	-54	-65	26.87	1.058	52	7.5	8.81	0.347	153	22.2
1TY1218-3E			26.87	1.058	49	7.1	8.81	0.347	239	34.7
1TY1218-7F			26.87	1.058	50	7.3	8.81	0.347	158	22.9
1TY1216-3F	22	72	40.79	1.606	19	2.8	20.04	0.789	74	10.7
2TY1216-6C			40.79	1.606	19	2.7	20.04	0.789	70	10.2
1TY1218-5C			40.79	1.606	21	3.0	20.04	0.789	71	10.3
1TY1216-5D	22	72	32.41	1.276	28	4.0	14.50	0.571	122	17.7
2TY1216-13C			32.41	1.276	28	4.0	14.50	0.571	121	17.5
2TY1216-18D			32.41	1.276	29	4.2	14.50	0.571	131	19.0
2TY1216-3E	22	72	26.87	1.058	42	6.1	8.81	0.347	189	27.4
1TY1218-2C			26.87	1.058	38	5.5	8.81	0.347	138	20.0
1TY1218-15E			26.87	1.058	42	6.1	8.81	0.347	161	23.4
1TY1216-9E	93	200	40.79	1.606	21	3.0	-	-	-	-
1TY1216-18F			-	-	-	-	20.04	0.789	60	8.7
1TY1218-13D			-	-	-	-	20.04	0.789	59	8.6
1TY1218-12C	93	200	32.41	1.276	27	3.9	14.50	0.571	97	14.0
1TY1218-5D			32.41	1.276	26	3.8	14.50	0.571	91	13.2
1TY1218-9F			32.41	1.276	26	3.8	14.50	0.571	91	13.2
1TY1216-2E	93	200	26.87	1.058	39	5.6	8.81	0.347	137	19.9
1TY1216-13E			26.87	1.058	38	5.5	8.81	0.347	130	18.9
1TY1218-17D			26.87	1.058	37	5.4	8.81	0.347	125	18.2
2TY1216-16E	135	275	40.79	1.606	14	2.1	-	-	-	-
1TY1218-7C			-	-	-	-	20.04	0.789	51	7.4
1TY1218-9E			-	-	-	-	20.04	0.789	53	7.7
2TY1216-2C	135	275	-	-	-	-	14.50	0.571	72	10.4
2TY1216-8D			32.41	1.276	23	3.4	-	-	-	-
1TY1218-5F			32.41	-	-	-	14.50	0.571	71	10.3
2TY1216-9C	135	275	-	-	-	-	8.81	0.347	113	16.4
2TY1216-11C			-	-	-	-	8.81	0.347	111	16.1
2TY1218-6F			-	-	-	-	-	-	-	-
1TY1216-18D			26.9	1.058	36	5.23				
1TY1216-17E			20.0	0.789	50	7.32				
2TY1216-14D			20.0	0.789	54	7.87				
1TY1218-11D			20.0	0.789	51	7.45				
1TY1216-4D			14.5	0.571	74	10.7				
1TY1216-5F			14.5	0.571	77	11.2				
2TY1216-5E			14.5	0.571	77	11.1				
1TY1216-11E			8.8	0.347	108	15.6				
2TY1216-8C			8.8	0.347	112	16.2				
2TY1216-14E			8.8	0.347	111	16.1				

TABLE 53

COLUMN BUCKLING DATA FOR DRY AND WET LAMINATE L1, LONGITUDINAL - A S/3501-5A

Specimen ID	Temperature ^{o}C	^{o}F	Column Length mm	in.	σ Buckling MPa	ksi	Column Length mm	in.	σ Buckling MPa	ksi
1TJ1282-9B	22D	72D	40.8	1.606	117.2	17.0	20.0	.789	372.3	54.0
-15B					106.2	15.4			338.5	49.1
-24C					101.4	14.7			346.1	50.2
1TJ1282-31A	22D	72D	32.4	1.276	162.0	23.5	14.5	.571	493.7	71.6
-31B					157.9	22.9			466.8	67.7
-22C					150.3	21.8			463.3	67.2
1TJ1282-12A	22D	72D	26.9	1.058	233.7	33.9	8.8	.347	515.0	74.7
-27A					219.9	31.9			440.6	63.9
-20C					237.2	34.4			500.6	72.6
1TJ1282-30A	135W	275W	40.8	1.606	102.7	14.9	20.0	.789	308.2	44.7
-16B					102.0	14.8			292.3	42.4
-20B					113.8	16.5			291.0	42.2
1TJ1282-22A	135W	275W	32.4	1.276	146.2	21.2	14.5	.571	302.0	43.8
-19B					149.6	21.7			355.1	51.5
-27B					150.3	21.8			370.9	53.8
1TJ1282-11A	135W	275W	26.9	1.058	187.5	27.2	8.8	.347	345.4	50.1
-18B					200.0	29.0			391.6	56.8
-4C					208.9	30.3			377.1	54.7

TABLE 54

COLUMN BUCKLING DATA FOR DRY AND WET LAMINATE L1, TRANSVERSE - A S/3501-5A

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	σBuckling MPa	σBuckling ksi	Column Length mm	Column Length in.	σBuckling MPa	σBuckling ksi
1TJ1282-5D	22D	72D	40.8	1.506	83.4	12.1	20.0	.789	299.9	43.5
-12E					77.2	11.2			279.2	40.5
-5F					82.7	12.0			291.0	42.2
1TJ1282-14E	22D	72D	32.4	1.276	117.9	17.1	14.5	.571	384.0	55.7
-1F					115.8	16.8			404.7	58.7
-10F					128.2	18.6			422.6	61.3
1TJ1282-8D	22D	72D	26.9	1.058	186.2	27.0	8.8	.347	440.6	63.9
-3E					166.2	24.1			426.1	61.8
-9E					189.6	27.5			464.0	67.3
1TJ1282-2D	135W	275W	40.8	1.606	80.0	11.6	20.0	.789	243.4	35.3
-2F					80.0	11.6			255.1	37.0
-15F					82.7	12.0			244.1	35.4
1TJ1282-9D	135W	275W	32.4	1.276	119.3	17.3	14.5	.571	297.8	43.2
-14F					109.6	15.9			242.0	35.1
-16F					122.7	17.8			279.2	40.5
1TJ1282-13D	135W	275W	26.9	1.058	153.1	22.2	8.8	.347	308.2	44.7
-15E					152.4	22.1			288.9	41.9
-13F					153.1	22.2			321.3	46.6

TABLE 55

COLUMN BUCKLING DATA FOR DRY AND WET LAMINATE L2, LONGITUDINAL - A S/3501-5A

	Temperature		Column Length		σ Buckling		Column Length		σ Buckling	
Specimen ID	°C	°F	mm	in.	MPa	ksi	mm	in.	MPa	ksi
1TJ1283-4A	22D	72D	40.8	1.606	347.5	50.4	20.0	.789	841.8	122.1
-8B					321.3	46.6			854.3	123.9
-18C					314.4	45.6			822.5	119.3
1TJ1283-4B	22D	72D	32.4	1.276	459.9	66.7	14.5	.571	922.5	133.8
-10B					471.6[a]	68.4[a]			-	-
-4C					478.5	69.4			695.0	100.8
1TJ1245-9B	22D	72D	26.9	1.058	-	-	8.8	.347	954.9	138.5
1TJ1283-2A			-	-	-	-			794.3	115.2
-6B					681.2[a]	98.8[a]			-	-
-16B					587.4[a]	85.2[a]			-	-
-18B					506.8	73.5			848.1	123.0
1TJ1245-5B	135W	275W	40.8	1.606	94.5[b]	13.7[b]	20.0	.789	569.5	82.6
1TJ1283-15A					307.5[a]	44.6[a]			-	-
1TJ1283-13B					295.1	42.8			535.0	77.6
1TJ1240-1B	135W	275W	32.4	1.276	-	-	14.5	.571	459.9	66.7
1TJ1283-10A			-	-	-	-			557.8	80.9
-18A			-	-	-	-			515.0	74.7
-17B			-	-	-	-			521.2	75.6
2TJ1283-3A					439.9[a]	63.8[a]			-	-
-7A					409.5[a]	59.4[a]			-	-
1TJ1240-10B	135W	275W	26.9	1.058	-	-	8.8	.347	486.1	70.5
1TJ1283-6A					479.2[a]	69.5[a]			-	-
-15B			-	-	440.6[a]	63.9[a]			-	-
1TJ1245-7B			-	-	-	-			540.5	78.4
1TJ1283-5B			-	-	-	-			616.4	89.4
-17C			-	-	-	-			605.4	87.8

a - Specimen failed. Could not be tested at shorter length.

b - Specimen accidentally heated to 290°F (143°C)

TABLE 56

COLUMN BUCKLING DATA FOR DRY AND WET LAMINATE L2, TRANSVERSE - A S/3501-5A

Specimen ID	Temperature °C	°F	Column Length mm	in.	σ Buckling MPa	ksi	Column Length mm	in.	σ Buckling MPa	ksi
1TJ1283-7D	22D	72D	40.8	1.606	87.6	12.7	20.0	.789	248.9	36.1
-1E					68.3	9.9			222.0	32.2
-12E					78.6	11.4			238.6	34.6
1TJ1283-13D	22D	72D	32.4	1.276	118.6	17.2	14.5	.571	252.4	36.6
-14D					127.6	18.5			251.0	36.4
-9E					112.4	16.3			245.4	35.6
1TJ1240-2A	22D	72D	26.9	1.058	169.6	24.6	8.8	.347	244.8	35.5
1TJ1283-16D					164.1	23.8			239.9	34.8
-17E					165.5	24.0			255.8	37.1
1TJ1283-5D	135W	275W	40.8	1.606	68.3	9.9	20.0	.789	163.4	23.7
-6D					60.0	8.7			126.9	18.4
-8D					64.8	9.4			161.3	23.4
1TJ1240-1A	135W	275W	32.4	1.276	92.4	13.4	14.5	.571	162.0	23.5
1TJ1283-18D					95.2	13.8			175.1	25.4
-6E					86.9	12.6			150.3	21.8
1TJ1283-4D	135W	275W	26.9	1.058	122.0	17.7	8.8	.347	160.0	23.2
-12D					120.0	17.4[a]			-	-
2TJ1283-3B					117.2	17.0			173.1	25.1

a - Specimen failed. Could not be tested at shorter length.

TABLE 57

COLUMN BUCKLING DATA FOR DRY AND WET LAMINATE U1, LONGITUDINAL - AS/3501-5A

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi
2TJ1281-17A	22D	72D	26.87	1.058		43.6	8.81	0.347		161.7
-18A			26.87	1.058		50.1	8.81	0.347		170.2
-2B			26.87	1.058		48.1	8.81	0.347		127.3
2TJ1281-1A	22W	72W	40.79	1.606	179	25.9	20.04	0.789	581	84.3
-7A			40.79	1.606	219	31.7	20.04	0.789	654	94.9
-4B			40.79	1.606	203	29.4	20.04	0.789	625	90.6
-8A			32.41	1.276	313	45.4	14.50	0.571	825	119.7
-7B			32.41	1.276	319	46.3	14.50	0.571	881	127.8
-11B			32.41	1.276	321	46.6	14.50	0.571	836	121.2
-10A			26.87	1.058	433	62.8	8.81	0.347	934	135.5
-15B			26.87	1.058	420	60.9	8.81	0.347	898	130.3
-17B			26.87	1.058	436	63.2	8.81	0.347	845	122.5
2TJ1281-21A	135W	275W	40.79	1.606	184	26.7	20.04	0.789	452	65.5
-3B			40.79	1.606	181	26.2	20.04	0.789	412	59.8
-10B			40.79	1.606	185	26.9	20.04	0.789	460	66.7
-1B			32.41	1.276	228	33.0	-	-	-	-
-8B			-	-	-	-	14.50	0.571	475	68.9
-12B			32.41	1.276	253	36.7	14.50	0.571	463	67.2
-12A			-	-	-	-	8.81	0.347	522	75.7
-19A			-	-	-	-	8.81	0.347	517	75.0
-9B			26.87	1.058	342	49.6	-	-	-	-

TABLE 58

COLUMN BUCKLING DATA FOR DRY AND WET LAMINATE U1, TRANSVERSE - AS3501-5A

	Temperature		Column Length		σ Buckling		Column Length		σ Buckling	
Specimen ID	°C	°F	mm	in.	MPa	ksi	mm	in.	MPa	ksi
2TJ1281-3C	22D	72D	40.8	1.606	20.7	3.0	20	.789	80.0	11.6
-10C					21.4	3.1			77.9	11.3
-19D					21.4	3.1			76.5	11.1
2TJ1281-22C	22D	72D	32.4	1.276	33.1	4.8	14.5	.571	130.3	18.9
-6D					31.7	4.6			131.7	19.1
-18D					33.1	4.8			129.6	18.8
2TJ1281-6C	22D	72D	26.9	1.058	46.9	6.8	8.8	.347	217.9	31.6
-8D					44.1	6.4			209.6	30.4
-23D					50.3	7.3			174.4	25.3
2TJ1281-2D	135W	275W	40.8	1.606	15.9	2.3	20.0	.789	46.2	6.7
-3D						-			39.3	5.7
-5D					11.7	1.7			43.4	6.3
-11D					9.7	1.4[a]			-	-
-12D					-	-			37.2	5.4
2TJ1281-5C	135W	275W	32.4	1.276	-	-	14.5	.571	46.2	6.7
-9C					-	-			52.4	7.6
-14D					23.4	3.4[a]			-	-
2TJ1281-7C	135W	275W	26.9	1.058	-	-	8.8	.347	73.8	10.7
-14C					33.8	4.9			89.6	13.0
-7D					33.1	4.8			93.1	13.5
-15D					33.1	4.8			91.7	13.3

a - Specimen failed. Could not be tested at shorter length.

TABLE 59

AVERAGE BUCKLING STRENGTH OF T300/5208 LAMINATES AT 72°F (22°C) DRY AND 275°F (135°C) WET

Laminate Type	Column Length in.	Column Length mm	Longitudinal Average σ Buckling 72°F Dry ksi	Longitudinal Average σ Buckling 22°C Dry MPa	Longitudinal Average σ Buckling 275°F Wet ksi	Longitudinal Average σ Buckling 135°C Wet MPa	Percent Decrease 72°F(22°C) Dry 275°F(135°C) Wet	Transverse Average σ Buckling 72°F Dry ksi	Transverse Average σ Buckling 22°C Dry MPa	Transverse Average σ Buckling 275°F Wet ksi	Transverse Average σ Buckling 135°C Wet MPa	Percent Decrease 72°F(22°C) Dry To 275°F(135°C) Wet
	0 [a]	0 [a]	70.7	487.6	63.3	436.4	10	58.2	401.3	53.4	368.2	8
	0.347	8.8	58.4	402.6	52.3	360.6	10	56.1	386.8	49.0	337.8	13
Laminate	0.571	14.5	54.8	377.8	44.1	304.1	20	54.0	372.3	42.6	293.7	20
L1	0.789	20.0	50.1	345.4	44.8	308.9	11	41.3	284.8	39.7	273.7	4
Quasi-	1.058	26.9	32.4	223.4	34.0	234.4	-5	26.2	180.6	26.7	184.1	-2
Isotropic	1.276	32.4	24.0	165.5	23.0	158.6	4	18.7	128.9	18.9	130.3	-1
	1.606	40.8	15.8	108.9	15.6	107.6	1	12.5	86.2	12.5	86.2	-
	0 [a]	0 [a]	130.6	900.5	119.0	820.5	9	33.8	233.0	27.6	190.3	18
	0.347	8.8	144.8	998.4	96.8	667.4	33	31.6	217.9	27.7	191.0	12
Laminate	0.571	14.5	121.9	840.5	93.9	647.4	23	29.7	204.8	24.7	170.3	17
L2	0.789	20.0	106.7	735.7	103.8	715.7	3	27.6	190.3	24.1	166.2	13
67% - 0°	1.058	26.9	93.9	647.4	80.2	553.0	15	23.4	161.3	20.7	142.7	12
33% - ±45°	1.276	32.4	73.1	504.0	67.8	467.5	7	17.2	118.6	15.2	104.8	12
	1.606	40.8	47.6	328.2	48.6	335.1	-2	11.1	76.5	10.7	73.8	4
U1	0 [a]	0 [a]	143.3	988	72.4	400	49	30.0	207	19.1	132	36
0°	0.347	8.8	140.0	965	102.5	707	27	29.4	203	16.2	112	45
Unidirectional	0.571	14.5	134.3	926	81.2	560	39	19.0	131	10.3	71	46
	0.789	20.0	105.1	725	78.1	538	26	11.2	77	7.5	52	33
	1.058	26.9	67.9	468	60.9	420	10	6.8	47	-	-	-
	1.276	32.4	48.1	332	45.0	310	6	4.6	32	3.4	23	26
	1.606	40.8	32.0	221	31.4	216	1	3.0	21	2.1	14	30

a - Fully Supported

TABLE 60

AVERAGE BUCKLING STRENGTH OF A-S/3501-5A LAMINATES AT 72°F (22°C) DRY AND 275°F (135°C) WET

Laminate Type	Column Length in.	Column Length mm	Longitudinal Average σ Buckling 72°F Dry ksi D (W)	Longitudinal 22°C Dry MPa D (W)	Longitudinal 275°F Wet ksi	Longitudinal 135°C Wet MPa	Percent Decrease 72°F(22°C) Dry To 275°F(135°C) Wet	Transverse Average σ Buckling 72°F Dry ksi	Transverse 22°C Dry MPa	Transverse 275°F Wet ksi	Transverse 135°C Wet MPa	Percent Decrease 72°F(22°C) Dry To 275°F(135°C) Wet
	0 [a]	0 [a]	83.0	572.5	65.4	450.7	21	68.7	473.4	51.1	352.6	26
	0.347	8.8	70.4	485.4	53.9	371.6	23	64.3	443.6	44.4	306.1	31
Laminate	0.571	14.5	68.8	474.6	49.7	342.7	28	58.6	403.8	39.6	273.0	32
L1	0.789	20.0	51.1	352.3	43.1	297.2	16	42.1	290.0	35.9	247.[illegible]	15
Quasi-	1.058	26.9	33.4	230.3	28.8	198.8	14	26.2	180.6	22.2	152.8	15
Isotropic	1.276	32.4	22.7	156.5	21.6	148.7	5	17.5	120.7	17.0	117.2	3
	1.606	40.8	15.7	108.2	15.4	106.2	2	11.8	81.1	11.7	80.9	1
	0 [a]	0 [a]	138.2	953.1	72.5	499.9	48	43.8	301.8	26.2	180.9	40
	0.347	8.8	125.6	865.8	81.5	562.1	35	35.8	246.8	24.2	166.5	32
Laminate	0.571	14.5	117.3	808.8	74.5	513.5	36	36.2	249.6	23.6	162.5	35
L2	0.789	20.0	121.8	839.6	80.1	552.3	34	34.3	236.5	21.8	150.3	36
67% - 0°	1.058	26.9	85.8	591.8	66.7	459.9	22	24.1	166.4	17.4	119.7	28
33% - ±45°	1.276	32.4	68.2	470.0	61.6	424.7	10	17.3	119.5	13.3	91.5	23
	1.606	40.8	47.5	327.7	43.7	301.3	8	11.3	78.1	9.3	64.4	18
	0 [a]	0 [a]	155.6	1073	67.6	466	56 [c]	34.8	240	15.6	107	55
U1	0.347	8.8	153.0(141.2)	1054 (973)			-	29.1	201	12.6	87	57
0°-	0.571	14.5	(123.0)		68.0	469	45 [d]	18.9	130	7.1	49	62
	0.789	20.0	(90.0)		64.0	441	29 [d]	11.3	78	6.0	41	47
Unidirectional	1.058	26.9	47.3(54.77)	326 (378)			-	6.8	47	4.8	33	29
	1.276	32.4	(46.1)	(318)	34.8	240	24 [d]	4.7	32	3.4	23	27
	1.606	40.8	(29.0)	(200)	26.6	183	8 [d]	3.1	21	1.8	12	42

a - Fully Supported

b - For this laminate not all the tests were run at room temperature dry (D) some were tested wet (W)

c - Percent decreases from 22°C (72°F) Dry to 135°C (275°F) Wet

d - Percent decrease from 22°C (72°F) Wet to 135°C (275°F) Wet

TABLE 61a

COMPARISON OF AVERAGE BUCKLING STRENGTH (ksi) OF T300/5208 AND A-S/3501-5A LAMINATES AT 72°F DRY AND 275°F WET

Laminate Type	Column Length in.	Longitudinal 72°F Dry T300/5208 (D)	Longitudinal 72°F Dry A-S/3501-5A D (W)	Longitudinal 275°F Wet T300/5208	Longitudinal 275°F Wet A-S/3501-5A	Transverse 72°F Dry T300/5208	Transverse 72°F Dry A-S/3501-5A	Transverse 275°F Wet T300/5208	Transverse 275°F Wet A-S/3501-5A
	0 [a]	70.7	83.0	63.3	60.5	58.2	68.7	53.4	51.1
Laminate	0.347	58.4	70.4	52.3	53.9	56.1	64.3	49.0	44.4
L1	0.571	54.8	68.8	44.1	49.7	54.0	58.6	42.6	39.6
Quasi-	0.789	50.1	51.1	44.8	43.1	41.3	42.1	39.7	35.9
Isotropic	1.058	32.4	33.4	34.0	28.8	26.2	26.2	26.7	22.2
	1.276	24.0	22.7	23.0	21.6	18.7	17.5	18.9	17.0
	1.606	15.8	15.7	15.6	15.4	12.5	11.8	12.5	11.7
	0 [a]	130.6	138.2	119.0	72.5	33.8	43.8	27.6	26.2
Laminate	0.347	144.8	125.6	96.8	81.5	31.6	35.8	27.7	24.2
L2	0.571	121.9	117.3	93.9	74.5	29.7	36.2	24.7	23.6
67% - 0°	0.789	106.7	121.8	103.8	80.1	27.6	34.3	24.1	21.8
33% - ± 45°	1.058	93.9	85.8	80.2	66.7	23.4	24.1	20.7	17.4
	1.276	73.1	68.2	67.8	61.6	17.2	17.3	15.2	13.3
	1.606	47.6	47.5	48.6	43.7	11.1	11.3	10.7	9.3
	0	143.3	155.6	72.4	67.6	30.0	34.8	19.1	15.6
U1	0.347	140.0	153.0(141.2)	102.5	-	29.4	29.1	16.2	12.6
0° -	0.571	134.3	(123.0)	81.2	68.0	19.0	18.9	10.3	7.1
Unidirectional	0.789	105.1	(90.0)	78.1	64.0	11.2	11.3	7.5	6.0
	1.058	67.9	47.3(54.77)	60.9	-	6.8	6.8	-	4.8
	1.276	48.1	(46.1)	45.0	34.8	4.6	4.7	3.4	3.4
	1.606	32.0	(29.0)	31.4	26.6	3.0	3.1	2.1	1.8

a - Fully Supported

TABLE 61b

COMPARISON OF AVERAGE BUCKLING STRENGTH (MPa) OF T300/5208 AND A-S/3501-5A LAMINATES AT 22°C DRY AND 135°C WET

Laminate Type	Column Length in.	Longitudinal					Transverse			
		22°C Dry			135°C Wet		22°C Dry		135°C Wet	
		T300/ 5208 (D)	A-S 3501-5A (D)	(W)	T300/ 5208	A-S 3501-5A	T300/ 5208	A-S 3501-5A	T300/ 5208	A-S 3501-5A
	0 [a]	487.6	572.5		436.4	450.7	401.3	473.4	368.2	352.6
Laminate	8.8	402.6	485.4		360.6	371.6	386.8	443.6	337.8	306.1
L1	14.5	377.8	474.6		304.1	342.7	372.3	403.8	293.7	273.0
Quasi-	20.0	345.4	352.3		308.9	297.2	284.8	290.0	273.7	247.5
Isotropic	26.9	223.4	230.3		234.4	198.8	180.6	180.6	184.1	152.8
	32.4	165.5	156.5		158.6	148.7	128.9	120.7	130.3	117.2
	40.8	108.9	108.2		107.6	106.2	86.2	81.1	86.2	80.9
	0 [a]	900.5	953.1		820.5	499.9	233.0	301.8	190.3	180.9
	8.8	998.4	865.8		667.4	562.1	217.9	246.8	191.0	166.5
Laminate	14.5	840.5	808.8		647.4	513.5	204.8	249.6	170.3	162.5
L2	20.0	735.7	839.6		715.7	552.3	190.3	236.5	166.1	150.3
67% - 0°	26.9	647.4	591.8		553.0	459.9	162.3	166.4	142.7	119.7
33% - ± 45°	32.4	504.0	470.0		467.5	424.7	118.6	119.5	104.8	91.5
	40.8	328.2	327.7		335.1	301.3	76.5	78.1	73.8	64.4
U1	0 [a]	988	1073		499	466	207	240	132	107
	8.8	965	1054	(973)	707	-	203	201	112	67
	14.5	926	-		560	469	131	130	71	49
	20.0	725	-		538	441	77	78	52	41
	26.9	468	326	(378)	420	-	47	47	-	33
	32.4	332	-	(318)	310	240	32	32	23	23
	40.8	221		(200)	216	183	21	31	14	12

a - Fully supported

These two sets of specimens were subjected to column tests under test conditions of 135°C (275°F). The fully supported compression results are presented in Tables 62 and 63, and the column buckling data are tabulated in Tables 64 and 65. (Column curves are included in Section 5.) Examination of the data indicates that neither drying nor drying and reconditioning resulted in a significant difference in the column performance.

4.9 Effect of Non-Uniform Moisture Distribution on the Column Behavior

Two additional groups of column test specimens were moisture-conditioned in special fashion in order to obtain 1) high moisture content at the surfaces, low in the center, and (2) unsymmetrical moisture distribution, high at one surface and low at the other. Details of preparation and moisture distributions are described in Section 4.3. These specimens were identified NUM 1 and NUM 2, respectively.

Tests of the non-uniform moisture specimens were conducted at both 22°C (72°F) and at 135°C (275°F). Test results are presented in Tables 66 through 73. (Column curves are included in Section 5.)

Comparison of these test results with the scatter bands representing baseline data and with the theoretical column curves indicates no consistent trend attributable to non-uniform moisture distribution.

4.10 Effect of Microcracks on Column Behavior

To determine whether matrix damage due to prior loading resulting in microcracking would influence column behavior, a large group of T300/5208 specimens, fabricated in L1 and L2 layups of prepreg material designated "SY", was prepared by first applying tensile load to 80 percent, and in some cases to 90 percent, of the average tensile ultimate. The presence of microcracks following application of this pre-load was ascertained by making microstudies of a number of specimens of the different laminates. Microcracks were located in laminates L1I and L2T. "Wet" conditioned laminates appeared to have a higher density of cracks than the dry. However, no cracks were located in laminates L2L, although audible cracking sounds were prevalent during the tension preloading, especially to 90% of σ_{TU}. Moisture distributions for the tension preloaded laminates were obtained and are presented in Appendix C.

TABLE 62a

FULLY SUPPORTED COMPRESSION TEST RESULTS AT 275°F AFTER DRYING - T300/5208

Laminate Type	Specimen ID	Average Area in.^{2}	Ultimate Load P_{ult}, kip	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Secant Modulus[a] E_s, psi x 10^6	Failure[b] Location
L1-L	1TY1224-22A	0.0826	5.24	65.6	0.0103	6.4	6.7	G
	1TY1226-14B	0.0816	5.42	66.4	0.0105	6.3	6.9	G
	2TY1218-36B	0.0809	5.26	65.0	0.0103	6.3	6.7	G
L1-T	1TY1226-2D	0.0802	4.74	59.0	0.0087	6.8	7.4	G
	1TY1226-5E	0.0818	4.08	49.9	0.0077	6.5	6.9	G
	2TY1218-12E	0.0821	[illegible].54	55.2	0.0086	6.4	6.6	G
L2-L	1TY1225-3A	0.1214	15.30	126.0	0.0107	11.8	13.7	G
	1TY1225-14A	0.1216	15.48	127.3	0.0106	12.0	13.2	G
	2TY1226-5A	0.1213	16.54	136.4	0.0119	11.5	13.5	1/2 W
L2-T	2TY1225-6F	0.1211	3.53	29.1	0.0120	2.4	2.7	G
	2TY1225-8F	0.1219	3.35	27.5	0.0113	2.4	2.6	G
	2TY1226-8E	0.1220	3.87	31.7	0.0135	2.3	2.6	G
U1-L	1TY1216-13A	0.0814	9.44	116.0	0.0570	2.0	2.2	1/2 W
	1TY1216-10B	0.0820	8.48	103.4	0.0602[b]	1.7[b]	2.3[b]	1/2 W
	1TY1216-14B	0.0825	10.26	124.4	- [b]	- [b]	- [b]	1/2 W
	1TY1216-19B	0.0819	9.24	112.8	-	-	-	1/2 W
	2TY1216-7B	0.0823	11.64	141.4	0.0767	1.8	2.1	1/2 W
U1-T	1TY1216-6E	0.0813	2.00	24.6	0.0219	1.1	1.3	G
	1TY1216-8E	0.0817	2.00	24.4	0.0243	1.0	1.2	G
	1TY1216-8F	0.0804	2.15	26.7	0.0267	1.0	1.3	W

a - E_s at 70 ksi for L2-L and U1-L; E_s at 35 ksi for L1-L and L1-T; E_s at 17 ksi for L2-T and U1-T.

b - G - gage section one inch from tabs. W - between 1/2 and 1 specimen width (1-inch) away from tab.

1/2 W - between tab end and 1/2 width from tab end.

c - Extensometer slipped. Data not availab.e.

TABLE 62b

FULLY SUPPORTED COMPRESSION TEST RESULTS AT 135°F AFTER DRYING - T300/5208

Laminate Type	Specimen ID	Average Area mm^2	Ultimate Load P_{ult}, kN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Molulus[a] E_s, GPa	Failure Location
L1-L	1TY-1224-22A	53.3	24.1	452	0.0103	44	46	G
	1TY-1226-14B	52.6	24.1	458	0.0105	43	48	G
	2TY-1218-36B	52.2	23.4	448	0.0103	43	46	G
L1-T	1TY-1226-2D	51.7	21.1	407	0.0087	47	51	G
	1TY-1226-5E	52.8	18.1	344	0.0077	45	48	G
	2TY-1218-12E	53.0	20.2	381	0.0086	44	46	G
L2-L	1TY-1225-3A	78.3	68.1	869	0.0107	81	74	G
	1TY-1225-14A	78.5	68.9	878	0.0106	83	91	G
	2TY-1226-5A	78.3	73.6	940	0.0119	79	92	½W
L2-T	2TY-1225-6F	78.1	15.7	201	0.0120	16.5	19	G
	2TY-1225-8F	78.6	14.9	190	0.0113	16.5	18	G
	2TY-1226-8E	78.7	17.2	219	0.0135	15.8	18	G
U1-L	1TY-1216-13A	52.5	42.0	800	0.0570	13.8	15	½W
	1TY-1216-10B	52.9	37.7	713	0.0602	11.7	16	½W
	1TY-1216-14B	53.2	45.6	858	--b	--b	--b	½W
	1TY-1216-19B	52.8	41.1	778	--b	--b	--b	½W
	2TY-1216-7B	53.1	51.8	629	0.0767	12.4	14	½W
U1-T	1TY-1216-6E	52.5	8.9	170	0.0219	7.6	9.0	G
	1TY-1216-8E	52.7	8.9	168	0.0243	6.9	8.3	G
	1TY-1216-8F	51.9	9.6	184	0.0267	6.9	9.0	W

a - E_s at 482 MPa for L2-L and U1-L; E_s at 241 MPa for L1-1 and L1-T; E_s at 117 MPa for L2-T and U1-T.

b - Extensometer slipped, data not available.

TABLE 63a

FULLY SUPPORTED COMPRESSION TEST RESULTS AT 275°F AFTER DRYING AND RECONDITIONING - T300/5208

Laminate Type	Specimen ID	Average Area in.^{2}	Ultimate Load P_{ult}, kip	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure E_{sf}, psi x 10^6	Secant Modulus[a] E_s, psi x 10^6	Failure[b] Location
L1-L	2TY1218-30B	0.0818	4.04	49.3	0.0079	6.3	6.5	G
	1TY1224-31A	0.0829	4.34	52.4	0.0084	6.2	6.5	G
	1TY1226-28B	0.0818	4.55	55.6	0.0097	5.7	6.5	G
L1-T	2TY1218-18F	0.0816	3.[illegible]0	47.8	0.0074	6.5	6.9	G
	1TY1226-5D	0.0821	4.21	51.2	0.0079	6.5	7.0	G
	1TY1226-12D	0.0821	3.66	44.6	0.0067	6.7	7.0	G
L2-L	2TY1225-41A	0.1204	11.46	95.2	0.0094	10.1	12.8	G
	2TY1225-18B	0.1208	11.96	99.0	0.0087	11.4	13.0	G
	2TY1226-35A	0.1201	12.38	103.1	0.0083	12.5	13.0	G
L2-T	1TY1225-12C	0.1228	2.79	22.7	0.0123	1.8	2.0	G
	1TY1225-2D	0.1219	2.90	23.8	0.0129	1.8	2.0	G
	1TY1225-17D	0.1220	2.74	22.4	0.0118	1.9	2.1	G
U1-L	* 1TY1216-8A	0.0810	10480	129.4	0.0128	12.587	14.403	1/2 W
	* 1TY1216-38A	0.0803	7700	95.9	0.0068	13.971	14.474	1/2 W
	1TY1216-21B	0.0823	8440	102.6	0.0069	14.869	18.087	1/2 W
	* 1TY1218-23A	0.0792	9140	115.4	0.0089	12.977	14.381	1/2 W
	1TY1218-32A	0.0792	8320	105.4	0.0055	18.990	19.444	G
	* 1TY1218-34A	0.0793	10340	130.4	0.0098	13.246	15.234	1/2 W
U1-T	1TY1216-12E	0.0816	1.48	18.1	0.0315	0.6	0.6	G
	2TY1216-8E	0.0795	1.39	17.4	0.0287	0.6	0.6	G
	1TY1218-16D	0.0801	1.45	18.1	0.0302	0.6	0.6	G

a - E_s at 70 ksi for L2-L and U1-L; E_s at 35 ksi for L1-L and L1-T; E_s at 17 ksi for L2-T and U1-T.

b - G - gage section one inch from tabs.

TABLE 63b

FULLY SUPPORTED COMPRESSION TEST RESULTS AT 135°C AFTER DRYING AND RECONDITIONING - T300/5208

Laminate Type	Specimen ID	Average Area mm^2	Ultimate Load P_{ult}, kN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm in 50.8mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus[(a)] E_s, GPa	Failure Location[(b)]
L1-L	2TY-1218-30B	52.8	18.0	340	0.0079	43	45 @ 241 MPa	G
	1TY-1224-31A	53.5	19.3	361	0.0084	43	45 " "	G
	1TY-1226-28B	52.8	20.2	383	0.0097	39	45 " "	G
L1-T	2TY-1218-18F	52.6	17.3	330	0.0074	45	48 @ 241 MPa	G
	1TY-1226-5D	53.0	18.7	353	0.0079	45	48 " "	G
	1TY-1226-12D	53.0	16.3	308	0.0067	46	48 " "	G
L-2L	2TY-1225-41A	77.7	51.0	656	0.0094	70	88 @ 483 MPa	G
	2TY-1225-18B	77.9	53.2	683	0.0087	79	90 " "	G
	2TY-1226-35A	77.5	55.1	711	0.0083	86	90 " "	G
L2-T	1TY-1225-12C	79.2	12.4	156	0.0123	12	14 @ 117 MPa	G
	1TY-1225-2D	78.6	12.9	164	0.0129	12	14 " "	G
	1TY-1225-17D	78.7	12.2	154	0.0118	13	14 " "	G
U1-L	* 1TY-1216-8A	52.2	46617	892	0.0128	87	99	1/2 W
	* 1TY-1216-38A	51.8	34251	661	0.0068	96	100	1/2 W
	1TY-1216-21B	53.1	37452	707	0.0069	107	125	1/2 W
	* 1TY-1218-23A	51.1	40656	795	0.0089	89	99	1/2 W
	1TY-1218-32A	51.1	37009	726	0.0055	131	134	G
	* 1TY-1218-34A	51.2	45994	899	0.0098	91	105	1/2 W
U1-T	1TY-1216-12E	52.6	6.6	125	0.0315	3.9	4.1 @ 117 MPa	G
	2TY-1216-8E	51.3	6.2	120	0.0287	4.2	4.2 " "	G
	1TY-1218-16D	51.7	6.4	125	0.0302	4.1	4.1 " "	G

a - E_s at 482 MPa for L2-L and U1-L; E_s at 241 MPa for L1-1 and L1-T; E_s at 117 MPa for L2-T and U1-T.

b - G - gage section one inch from tabs

TABLE 64

COLUMN BUCKLING DATA AT 135°C(275°F) AFTER DRYING - T300/5208

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi	Column Lenghth mm	Column Lenghth in.	σ Buckling MPa	σ Buckling ksi
L1L										
1TY 1226-34B			40.8	1.606	116	16.8	20.0	0.789	344	49.9
1TY 1226-5A			40.8	1.606	104	15.1	20.0	0.789	350	50.7
1TY 1226-28A			40.8	1.606	111	16.1	20.0	0.789	349	50.6
1TY 1224-27A			32.4	1.276	159	23.0	14.5	0.571	362	52.5
2TY 1218-34A			32.4	1.276	159	23.0	14.5	0.571	361	52.3
2TY 1218-36A			32.4	1.276	154	22.4	14.5	0.571	370	53.7
2TY 1218-9B			26.9	1.058	226	32.8	8.8	0.347	416	60.4
2TY 1218-38B			26.9	1.058	225	32.7	8.8	0.347	369	53.5
1TY 1226-8A			26.9	1.058	220	32.0[a]	-	-	-	-
L1T										
1TY 1224-17C			40.8	1.606	88.3	12.8	20.0	0.789	283	41.0
1TY 1226-9F			40.8	1.606	86.2	12.5	20.0	0.789	284	41.2
1TY 1224-3F			40.8	1.606	85.5	12.4	20.0	0.789	281	40.8
1TY 1224-5C			32.4	1.276	126	18.3	14.5	0.571	328	47.6
2TY 1218-7C			32.4	1.276	122	17.7	14.5	0.571	291	42.2
2TY 1218-3D			32.4	1.276	125	18.1	14.5	0.571	342	49.6
2TY 1218-11D			26.9	1.058	177	25.6	8.8	0.347	352	51.0
2TY 1218-5E			26.9	1.058	179	26.0	8.8	0.347	375	54.4
1TY 1226-2E			26.9	1.058	179	26.0	8.8	0.347	347	50.4
L2L										
2TY 1225-9B			40.8	1.606	347	50.4	20.0	0.789	793	115.0
2TY 1225-40B			40.8	1.606	347	50.4	20.0	0.789	669	97.1
2TY 1225-4B			40.8	1.606	341	49.4[a]	-	-	-	-
2TY 1226-17A			32.4	1.276	412	59.7[a]	-	-	-	-
2TY 1225-37B			-	-	-	-	14.5	0.571	625	90.7
2TY 1225-17B			-	-	-	-	14.5	0.571	697	101.1

a - Specimen failed; could not be tested at shorter length

TABLE 64

COLUMN BUCKLING DATA AT 135°C (275°F) AFTER DRYING - T300/5208 (Continued)

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi
L2L										
2TY 1225-30B			26.9	1.058	504	73.1[a]	-	-	-	-
1TY 1225-37B			-	-	-	-	8.8	0.347	758	109.9
1TY 1225-28B			-	-	-	-	8.8	0.347	641	93.0
L2T										
1TY 1225-10C			40.8	1.606	75.2	10.9	20.0	0.789	177	25.7
1TY 1225-14C			40.8	1.606	73.1	10.6	20.0	0.789	174	25.3
2TY 1225-4E			40.8	1.606	77.2	11.2	20.0	0.789	190	27.6
2TY 1226-9E			32.4	1.276	110	16.0	14.5	0.571	193	28.0
2TY 1225-16F			32.4	1.276	105	15.3	14.5	0.571	179	25.9
2TY 1225-7F			32.4	1.276	108	15.6	14.5	0.571	179	25.9
2TY 1226-2E			26.9	1.058	158	22.8[a]	-	-	-	-
2TY 1226-13D			-	-	-	-	8.8	0.347	189	27.4
2TY 1225-15E			-	-	-	-	8.8	0.347	188	27.3
J1L										
1TY 1216-25B			40.8	1.606	223	32.3	20.0	0.789	683	99.0
1TY 1216-26B			40.8	1.606	234	33.9	20.0	0.789	736	106.8
1TY 1218-25A			40.8	1.606	227	33.0	20.0	0.789	669	97.0
2TY 1216-6A			32.4	1.276	324	47.0	14.5	0.571	847	122.8
2TY 1216-1B			32.4	1.276	316	45.8	14.5	0.571	836	121.2
1TY 1218-35A			32.4	1.276	328	47.5	14.5	0.571	895	129.8
2TY 1216-10B			-	-	-	-	8.8	0.347	883	128.1
2TY 1216-11B			26.9	1.058	452	65.5	8.8	0.347	854	123.9
2TY 1216-14B			26.9	1.058	456	66.2[a]	-	-	-	-
U1T										
2TY 1216-4E			40.8	1.606	18	2.6	20.0	0.789	67	9.7
2TY 1216-12G			40.8	1.606	17	2.4	20.0	0.789	70	10.2

a - Specimen failed; could not be tested at shorter length

TABLE 64

COLUMN BUCKLING DATA AT 135°C (275°F) AFTER DRYING - T300/5208 (Continued)

Specimen ID	Temperature		Column Length		σ Buckling		Column Length		σ Buckling	
	°C	°F	mm	in.	MPa	ksi	mm	in.	MPa	ksi
1TY 1218-4F			40.8	1.606	19	2.8	20.0	0.789	70	10.1
1TY 1216-13F			32.4	1.276	29	4.2	14.5	0.571	112	16.3
2TY 1216-18E			32.4	1.276	30	4.3	14.5	0.571	115	16.7
1TY 1218-11E			32.4	1.276	29	4.2	14.5	0.571	108	15.6
1TY 1218-3D			26.9	1.058	42	6.1	8.8	0.347	165	24.0
1TY 1218-7D			26.9	1.058	41	5.9	8.8	0.347	172	25.0
1TY 1218-10D			26.9	1.058	41	5.9	8.8	0.347	172	24.9

a - Specimen failed; could not be tested at shorter length

TABLE 65

COLUMN BUCKLING DATA AT 135°C (275°F) AFTER DRYING AND RECONDITIONING - T300/5208

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi
L1L										
1TY 1224-19A			40.79	1.606	106	15.4	20.04	0.789	325	47.2
1TY 1224-25A			40.79	1.606	107	15.5	20.04	0.789	319	46.2
1TY 1224-5B			40.79	1.606	106	15.4	20.04	0.789	343	49.8
1TY 1224-28B			32.41	1.276	160	23.2	14.50	0.571	392	56.8
1TY 1226-10B			32.41	1.276	157	22.8	14.50	0.571	321	46.6
1TY 1226-22B			32.41	1.276	156	22.6	14.50	0.571	334	48.4
2TY 1218-3G			26.87	1.058	211	30.6	8.81	0.347	379	55.0
1TY 1224-2B			26.87	1.058	215	31.2	8.81	0.347	383	55.6
1TY 1226-13B			26.87	1.058	208	30.1	8.81	0.347	332	48.2
L1T										
1TY 1226-11C			40.79	1.606	82	11.9	20.04	0.789	248	36.0
1TY 1226-16C			40.79	1.606	74	10.8	20.04	0.789	247	35.8
1TY 1226-10D			40.79	1.606	83	12.0	20.04	0.789	202	29.3
1TY 1224-5E			32.41	1.276	123	17.8	14.50	0.571	317	46.0
1TY 1224-15E			32.41	1.276	130	18.8	14.50	0.571	285	41.4
1TY 1226-19E			32.41	1.276	121	17.6	14.50	0.571	283	41.0
2TY 1218-10D			26.87	1.058	170	24.6	8.81	0.347	296	43.0
1TY 1226-13C			26.87	1.058	175	25.4	8.81	0.347	300	43.5
1TY 1226-4F			26.87	1.058	170	24.6	8.81	0.347	260	37.7
L2L										
2TY 1225-10A			-	-	-	-	20.04	0.789	648	94.0
2TY 1225-39B			40.79	1.606	325	47.2[a]	-	-	-	-
2TY 1226-7B			-	-	-	-	20.04	0.789	632	91.7
1TY 1225-38A			-	-	-	-	14.50	0.571	609	88.3
2TY 1225-26A			32.41	1.276	446	64.7[a]	-	-	-	-
2TY 1225-19B			-	-	-	-	14.50	0.571	688	99.8

a - Specimen failed; could not be tested at shorter length

TABLE 65

COLUMN BUCKLING DATA AT 135°C (275°F) AFTER DRYING AND RECONDITIONING - T300/5208 (Continued)

Specimen ID	Temperature		Column Length		σ Buckling		Column Length		σ Buckling	
	°C	°F	mm	in.	MPa	ksi	mm	in.	MPa	ksi
2TY 1226-31A			-	-	-	-	14.50	0.571	653	94.7
1TY 1225-4B			-	-	-	-	8.81	0.347	740	107.3
1TY 1225-12B			-	-	-	-	8.81	0.347	645	93.6
1TY 1225-24B			26.87	1.058	538	78.1[a]	-	-	-	-
2TY 1225-33A			-	-	-	-	8.81	0.347	614	89.1
L2T										
1TY 1225-6D			40.79	1.606	69	10.0	20.04	0.789	151	21.9
2TY 1225-14C			40.79	1.606	66	9.6	20.04	0.789	139	20.1
2TY 1226-3E			40.79	1.606	102	14.8	20.04	0.789	144	20.9
1TY 1225-1E			32.41	1.276	102	14.8	14.50	0.571	152	22.1
2TY 1226-14D			32.41	1.276	99	14.4	14.50	0.571	162	23.5
2TY 1226-11F			32.41	1.276	105	15.3	14.50	0.571	150	21.7
2TY 1225-7E			26.87	1.058	134	19.4[a]	-	-	-	-
2TY 1225-3F			-	-	-	-	8.81	0.347	148	21.4
2TY 1226-1C			-	-	-	-	8.81	0.347	152	22.0
2TY 1226-2F			26.87	1.058	123	17.8	8.81	0.347	153	22.2
U1L										
1TY 1216-38B			40.8	1.606	228.9	33.2	20.0	.789	658.4	92.5
1TY 1216-23B			40.8	1.606	228.9	33.2	20.0	.789	655.0	95.0
1TY 1218-16B			40.8	1.606	228.9	32.0	20.0	.789	672.9	97.6
1TY 1216-33B			32.4	1.276	329.5	47.8	14.5	.571	726.0	105.3
2TY 1216-23A			32.4	1.276	337.8	49.0	14.5	.571	737.0	106.9
2TY 1216-31A			32.4	1.276	331.6	48.1	14.5	.571	751.5	109.0
1TY 1216-16B			26.9	1.058	459.2	66.6	8.8	.347	624.6	90.6
2TY 1216-16B			26.9	1.058	438.5	63.6	8.8	.347	776.3	112.6
2TY 1216-30B			26.9	1.058	463.3	67.2	8.8	.347	793.6	115.1

a - Specimen failed; could not be tested at shorter length

TABLE 65

COLUMN BUCKLING DATA AT 135°C (275°F) AFTER DRYING AND RECONDITIONING - T300/5208 (Continued)

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi
U1T										
1TY 1216-12D			40.79	1.606	17	2.4[a]	-	-	-	-
1TY 1216-7E			-	-	-	-	20.04	0.789	50	7.2
1TY 1216-12F			-	-	-	-	20.04	0.789	54	7.9
1TY 1218-18F			-	-	-	-	20.04	0.789	52	7.6
1TY 1216-5C			32.41	1.276	24	3.5[a]	-	-	-	-
1TY 1216-18C			-	-	-	-	14.50	0.571	73	10.6
1TY 1216-18C			32.41	1.276	22	3.2	14.50	0.571	75	10.9
1TY 1218-3F			-	-	-	-	14.50	0.571	76	11.0
2TY 1216-9E			26.87	1.058	30	4.3	8.81	0.347	119	17.3
1TY 1218-1C			26.87	1.058	33	4.8	8.81	0.347	102	14.8
1TY 1218-8C			26.87	1.058	36	5.2[a]	-	-	-	-
1TY 1218-17E			-	-	-	-	8.81	0.347	113	16.4

a - Specimen failed; could not be tested at shorter length

TABLE 66

COLUMN BUCKLING DATA FOR LAMINATE L1, LONGITUDINAL SPECIMENS HAVING A NON-UNIFORM, PARABOLIC MOISTURE DISTRIBUTION - T300/5208

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in	σ Buckling MPa	σ Buckling ksi
2TY-1224-20A	22	72	--	--	--	--	20.04	0.789	370	53.6
1TY-1226-14A			--	--	--	--	20.04	0.789	338	49.0
1TY-1226-3G			--	--	--	--	20.04	0.789	354	51.3
2TY-1218-5B			--	--	--	--	8.81	0.347	438	63.5
2TY-1218-40B			--	--	--	--	8.81	0.347	418	60.6
2TY-1218-30A	135	275	40.79	1.606	104	15.1	20.04	0.789	305	44.3
1TY-1224-15B			40.79	1.606	112	16.2	20.04	0.789	310	45.0
1TY-1224-36B			40.79	1.606	108	15.6	20.04	0.789	292	42.4
2TY-1218-8A			32.41	1.276	152	22.0	8.81	0.347	353	51.2
2TY-1218-18B			32.41	1.276	152	22.1	8.81	0.347	350	50.7
1TY-1224-29A			32.41	1.276	144	20.9	8.81	0.347	317	46.0

TABLE 67

COLUMN BUCKLING DATA FOR LAMINATE L2, LONGITUDINAL SPECIMENS HAVING A NON-UNIFORM, PARABOLIC MOISTURE DISTRIBUTION - T300/5208

Specimen ID	Temperature °C	°F	Column Length mm	in	σ Buckling MPa	ksi	Column Length mm	ksi	σ Buckling MPa	ksi
1TY-1225-1A	22	72	--	--	--	--	20.04	0.789	808	117.2
2TY-1225-2B			--	--	--	--	20.04	0.789	806	116.9
2TY-1225-20B			--	--	--	--	20.04	0.789	822	119.2
1TY-1225-10A			--	--	--	--	8.81	0.347	702	101.8
2TY-1226-2A			--	--	--	--	8.81	0.347	685	99.3
2TY-1226-33B			--	--	--	--	8.81	0.347	703	101.9
1TY-1225-41B	135	275	40.79	1.606	316	45.9	20.04	0.789	658	95.4
2TY-1226-28B			40.79	1.606	309	44.8	20.04	0.789	661	95.9
2TY-1226-34B			40.79	1.606	327	47.4	20.04	0.789	669	97.0
1TY-1225-17B			32.41	1.276	443	64.3	8.81	0.347	574	83.2
2TY-1226-6A			32.41	1.276	408	59.2	8.81	0.347	487	70.7
2TY-1226-1G			32.41	1.276	433	62.8	8.81	0.347	543	78.7

TABLE 68

COLUMN BUCKLING DATA FOR LAMINATE L1, LONGITUDINAL SPECIMENS HAVING
A NON-UNIFORM, PARABOLIC MOISTURE DISTRIBUTION - AS/3501-5A

Specimen ID	Temperature		Column Length		σ Buckling		Column Length		σ Buckling	
	°C	°F	mm	in.	MPa	ksi	mm	in	MPa	ksi
1TJ-1282-13A	22W	72W	--	--	--	--	20.04	0.789	341	49.5
1TJ-1282-20A			--	--	--	--	20.04	0.789	346	50.2
1TJ-1282-16C			--	--	--	--	20.04	0.789	350	50.8
1TJ-1282-15A			--	--	--	--	8.81	0.347	485	70.3
1TJ-1282-4B			--	--	--	--	8.81	0.347	476	69.0
1TJ-1282-29C			--	--	--	--	8.81	0.347	496	71.9
1TJ-1282-1B	135W	275W	40.79	1.606	87	12.6	20.04	0.789	251	36.4
1TJ-1282-13B			40.79	1.606	97	14.0	20.04	0.789	274	39.8
1TJ-1282-25B			40.79	1.606	94	13.7	20.04	0.789	300	43.5
1TJ-1282-2A			32.41	1.276	139	20.2	8.81	0.347	341	49.5
1TJ-1282-3A			32.41	1.276	137	19.8	8.81	0.347	301	43.7
1TJ-1282-1G			32.41	1.276	132	19.1	8.81	0.347	325	47.1

TABLE 69

COLUMN BUCKLING DATA FOR LAMINATE L2, LONGITUDINAL SPECIMENS HAVING A NON-UNIFORM, PARABOLIC MOISTURE DISTRIBUTION - AS/3501-5A

Specimen ID	Temperature		Column Length		σ Buckling		Column Length		σ Buckling	
	°C	°F	mm	in.	MPa	ksi	mm	in	MPa	ksi
1TJ-1245-8B	22W	72W	40.79	1.606	329	47.7	20.04	0.789	707	102.6
1TJ-1283-5A			40.79	1.606	322	46.7	20.04	0.789	648	94.0
1TJ-1283-12A			40.79	1.606	317	46.0	20.04	0.789	666	96.6
1TJ-1240-4B			40.79	1.606	324	47.2	20.04	0.789	721	104.6
1TJ-1283-7C			40.79	1.606	326	47.3	20.04	0.789	712	103.2
1TJ-1283-14A			32.41	1.276	429	62.2	8.81	0.347	636	92.2
1TJ-1283-17A	135W	275W	40.79	1.606	309	44.8	20.04	0.789	585	84.8
1TJ-1283-14C			40.79	1.606	281	40.7	20.04	0.789	564	81.8
2TJ-1283-10A			40.79	1.606	269	39.0	20.04	0.789	521	75.6
1TJ-1240-6B			32.41	1.276	385	55.9	8.81	0.347	485	70.3
1TJ-1283-11C			32.41	1.276	371	53.8	--	--	--	--
1TJ-1283-12C			--	--	--	--	8.81	0.347	478	69.3

TABLE 70

COLUMN BUCKLING DATA FOR LAMINATE L1, LONGITUDINAL SPECIMENS HAVING A NON-UNIFORM, LINEAR MOISTURE DISTRIBUTION - T300/5208

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi
2TY-1218-15B	22	72	40.79	1.606	108	15.6	20.04	0.789	347	50.4
1TY-1224-2A			40.79	1.606	115	16.7	20.04	0.789	332	48.2
1TY-1224-8B			40.79	1.606	108	15.6	20.04	0.789	362	52.5
2TY-1218-25A			32.41	1.276	160	23.2	8.81	0.347	401	58.2
1TY-1226-16B			32.41	1.276	164	23.8	8.81	0.347	430	62.4
2TY-1218-32A	135	275	40.79	1.606	103	14.9	20.04	0.789	331	48.0
1TY-1224-11A			40.79	1.606	108	15.6	20.04	0.789	345	50.1
1TY-1224-25B			40.79	1.606	111	16.1	20.04	0.789	332	48.1
2TY-1218-25B			32.41	1.276	153	22.2	8.81	0.347	398	57.7
1TY-1224-13A			32.41	1.276	159	23.1	8.81	0.347	363	52.6
1TY-1224-17A			32.41	1.276	166	24.1	8.81	0.347	356	51.7

TABLE 71

COLUMN BUCKLING DATA FOR LAMINATE L2, LONGITUDINAL SPECIMENS HAVING A NON-UNIFORM, LINEAR MOISTURE DISTRIBUTION - T300/5208

Specimen ID	Temperature		Column Length		σ Buckling		Column Length		σ Buckling	
	°C	°F	mm	in	MPa	ksi	mm	in	MPa	ksi
1TY-1225-1G	22	72	40.79	1.606	341	49.5	20.04	0.789	776	112.6
1TY-1225-26B			32.41	1.276	471	68.3	20.04	0.789	823	119.4
2TY-1226-34A			--	--	--	--	20.04	0.789	685	99.3
1TY-1225-19A			--	--	--	--	8.81	0.347	678	98.3
1TY-1225-40B			--	--	--	--	8.81	0.347	701	101.6
2TY-1225-13A	135	275	40.79	1.606	327	47.4	--	--	--	--
2TY-1225-26B			40.79	1.606	336	48.7	20.04	0.789	747	108.4
2TY-1226-37B			--	--	--	--	20.04	0.789	693	100.5
1TY-1225-11A			--	--	--	--	8.81	0.347	614	89.0
1TY-1225-26A			--	--	--	--	8.81	0.347	632	91.7
1TY-1225-5B			--	--	--	--	8.81	0.347	534	77.4

TABLE 72

COLUMN BUCKLING DATA FOR LAMINATE L1, LONGITUDINAL SPECIMENS HAVING A NON-UNIFORM, LINEAR MOISTURE DISTRIBUTION - AS/3501-5A

Specimen ID	Temperature		Column Length		σ Buckling		Column Length		σ Buckling	
	^oC	^oF	mm	in.	MPa	ksi	mm	in.	MPa	ksi
1TJ-1282-9A	22W	72W	40.79	1.606	113	16.4	20.04	0.789	361	52.4
1TJ-1282-17A			40.79	1.606	111	16.1	20.04	0.789	361	52.4
1TJ-1282-23C			40.79	1.606	98	14.2	20.04	0.789	296	42.9
1TJ-1282-1C			32.41	1.276	136	19.7	8.81	0.347	401	58.2
1TJ-1282-15C			32.41	1.276	157	22.7	8.81	0.347	386	56.0
1TJ-1282-6G			32.41	1.276	132	19.1	8.81	0.347	427	61.9
1TJ-1282-5A	135W	275W	40.79	1.606	104	15.1	20.04	0.789	316	45.9
1TJ-1282-8A			40.79	1.606	100	14.5	20.04	0.789	321	46.6
1TJ-1282-5B			40.79	1.606	108	15.6	20.04	0.789	347	50.3
1TJ-1282-6B			32.41	1.276	157	22.7	8.81	0.347	444	64.4
1TJ-1282-11C			32.41	1.276	139	20.2	8.81	0.347	428	62.1
1TJ-1282-26C			32.41	1.276	143	20.7	8.81	0.347	371	53.8

TABLE 73

COLUMN BUCKLING DATA FOR LAMINATE L2, LONGITUDINAL SPECIMENS HAVING A NON-UNIFORM, LINEAR MOISTURE DISTRIBUTION - AS/3501-5A

Specimen ID	Temperature		Column Length		σ Buckling		Column Length		σ Buckling	
	°C	°F	mm	in.	MPa	ksi	mm	in.	MPa	ksi
1TJ-1283-12B	22	72	--	--	--	--	20.04	0.789	683	99.1
1TJ-1283-8C			--	--	--	--	20.04	0.789	663	96.1
1TJ-1283-3B			--	--	--	--	8.81	0.347	689	100.0
1TJ-1283-13C			--	--	--	--	8.81	0.347	729	105.7
1TJ-1240-3B	135	275	--	--	--	--	20.04	0.789	632	91.7
1TJ-1240-7B			40.79	1.606	316	45.8	20.04	0.789	650	94.3
1TJ-1283-13A			40.79	1.606	300	43.5	--	--	--	--
1TJ-1240-2B			--	--	--	--	8.81	0.347	614	89.1
1TJ-1283-7A			--	--	--	--	8.81	0.347	512	74.2

These laminates attained a slightly higher equilibrium moisture content in a shorter period of time. The higher moisture content can in part be attributed to a higher resin content. Results of the optical microscopy study are presented in Appendix D.

Because the "SY" was not the same manufacturer's batch as the baseline tests, a number of the same specimens which were not precracked were tested under fully-supported compression and under column load at room temperature conditions to evaluate batch variability and provide an indication of data scatter. Results of these tests are given in Tables 74 through 77. Comparison with the baseline test data indicates no discernible difference due to the material batch.

Column tests of the precracked specimens were conducted at both room temperature and 135°C (275°F). Tables 78 through 80 present the results of these tests. (Column curves are presented in Section 5.) Comparison with the baseline data indicates no large or consistent difference which can be attributed to precracking.

TABLE 74a

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR 72°F, DRY - T300/5208 (BATCH SY)

Laminate Type	Specimen ID	Average Area in.^{2}	Ultimate Load P_{ult}, kip	Ultimate Stress σ_{ult}, ksi	Ultimate Strain ϵ_{ult}, in./in. in 2 in.	Secant Modulus at Failure, E_{sf}, psi x 10^6	Secant[a] Modulus E_s, psi x 10^6	Failure[b] Location
L1-L	1SY1424-3A	0.0815	6.51	79.9	0.0130	6.1	7.1	G
	1SY1424-7A	0.0817	6.55	80.2	0.0130	6.2	6.3	G
	1SY1424-18A	0.0811	5.65	69.7	0.0118	5.9	6.9	G
	1SY1424-19A	0.0816	6.27	76.8	0.0112	6.9	7.0	G
	1SY1424-20A	0.0816	6.36	77.9	0.0126	6.2	7.0	W
	1SY1424-21A	0.0815	6.30	77.3	0.0129	6.0	6.7	1/2 W
	1SY1424-26A	0.0812	6.20	76.4	0.0120	6.4	7.1	G
	2SF1424-1A	0.0787	5.14	65.3	0.0095	6.9	7.1	G
	2SF1424-5A	0.0786	5.41	68.8	0.0102	6.7	6.9	G
	2SF1424-26A	0.0800	5.24	65.5	0.0100	6.6	7.3	G
L2-L	1SY1423-2A	0.1265	16.98	134.3	0.0226	5.9	6.5	G
	1SY1423-8A	0.1255	17.14	136.6	0.0240	5.7	6.3	G
	1SY1423-11A	0.1264	17.60	139.2	0.0250	5.6	6.4	G
	1SY1423-18A	0.1259	17.70	140.6	0.0255	5.5	6.5	1/2 W
	2SY1423-18A	0.1239	18.10	146.0	0.0255	5.7	6.3	G
	2SY1423-19A	0.1243	15.74	126.6	0.0220	5.8	5.9	G
	2SY1423-32B	0.1236	18.54	150.1	0.0260	5.8	6.7	1/2 W
	2SY1423-37B	0.1248	18.90	151.4	0.0268	5.6	6.7	G
	2SY1423-48B	0.1248	17.10	137.0	0.0238	5.8	6.6	G
	2SY1423-58B	0.1239	17.78	143.4	0.0248	5.8	6.5	G
L2-T	1SY1423-3C	0.1257	4.16	33.1	0.0138	2.4	2.5	G
	1SY1423-4C	0.1245	4.35	35.0	0.0144	2.4	2.5	W
	1SY1423-8C	0.1237	4.19	33.8	0.0136	2.5	2.7	G
	2SY1423-6C	0.1252	4.04	32.3	0.0130	2.5	2.6	G
	2SY1423-10C	0.1253	4.02	32.1	0.0131	2.5	2.6	G
	2SY1423-13C	0.1256	4.08	32.5	0.0133	2.4	2.6	G
	2SY1423-20D	0.1257	4.32	34.4	0.0147	2.3	2.9	G
	2SF1423-34D	0.1263	3.84	30.4	0.0122	2.5	2.6	G
	2SF1423-37D	0.1260	3.71	29.4	0.0126	2.3	2.9	G
	2SF1423-37E	0.1260	4.07	32.3	0.0135	2.4	2.6	G

a - E_s at 70 ksi for L2-L and L1-L; E_s at 17 ksi for L2-T

b - G - gage section one inch from tabs. W - between 1/2 and 1 specimen width (1-inch) away from tab.

1/2 W - between tab end and 1/2 width from tab end.

TABLE 74b

FULLY SUPPORTED COMPRESSION TEST RESULTS FOR 22°C, DRY - T300/5208 (BATCH SY)

Laminate Type	Specimen ID	Average Area mm^2	Ultimate Load P_{ult}, kN	Ultimate Stress σ_{ult}, MPa	Ultimate Strain ϵ_{ult}, mm/mm in 50.8 mm	Secant Modulus at Failure E_{sf}, GPa	Secant Modulus[a] E_s, GPa	Failure Location
L1-L	1SY1424-3A	52.6	29.0	551	0.0130	42.1	49.0	G
	1SY1424-7A	52.7	29.1	553	0.0130	42.7	43.4	G
	1SY1424-18A	52.3	25.1	481	0.0118	40.7	47.6	G
	1SY1424-19A	52.6	27.9	530	0.0112	47.6	48.3	G
	1SY1424-20A	52.6	28.3	537	0.0126	42.7	48.3	W
	1SY1424-21A	52.6	28.0	533	0.0129	41.4	46.2	1/2 W
	1SY1414-26A	52.4	27.6	527	0.0120	44.1	49.0	G
	2SY1424-1A	50.8	22.9	450	0.0095	47.6	49.0	G
	2SY1424-5A	50.7	24.1	474	0.0102	46.2	47.6	G
	2SY1424-26A	51.6	23.3	452	0.0100	45.5	50.3	G
L2-L	1SY1424-2A	81.6	75.5	926	0.0226	40.7	44.8	G
	1SY1424-8A	81.0	76.2	942	0.0240	39.3	43.4	G
	1SY1424-11A	81.5	78.3	960	0.0250	38.6	44.1	G
	1SY1424-18A	81.2	78.7	969	0.0255	37.9	44.8	1/2 W
	2SY1423-18A	80.0	80.5	1010	0.0255	39.3	43.4	G
	2SY1423-19A	80.2	70.0	873	0.0220	40.0	40.7	G
	2SY1423-32B	79.7	82.5	1030	0.0260	40.0	46.2	1/2 W
	2SY1423-37B	80.6	84.1	1040	0.0268	38.6	46.2	G
	2SY1423-48B	80.5	76.1	945	0.0238	40.0	45.5	G
	2SY1423-58B	80.0	79.1	989	0.0248	40.0	44.8	G
L2-T	1SY1423-3C	81.1	18.5	228	0.0138	16.5	17.2	G
	1SY1423-4C	80.3	19.3	241	0.0144	16.5	17.2	W
	1SY1423-8C	79.8	18.6	233	0.0136	17.2	18.6	G
	2SY1423-6C	80.8	18.0	223	0.0130	17.2	17.9	G
	2SY1423-10C	80.8	17.9	221	0.0131	17.2	17.9	G
	2SY1423-13C	81.0	18.1	224	0.0133	16.5	17.9	G
	2SY1423-20D	81.1	19.2	237	0.0147	15.9	20.0	G
	2SY1423-34D	81.5	17.1	210	0.0122	17.2	17.9	G
	2SY1423-37D	81.3	16.5	203	0.0126	15.9	20.0	G
	2SY1423-37E	81.3	18.1	223	0.0135	16.5	17.9	G

a - E_s at 482 MPa for L2-L, L1-L; E_s at 117 MPa for L2-T

TABLE 75

COLUMN BUCKLING DATA FOR DRY LAMINATE L1, LONGITUDINAL AT 22°C (72°F) - T300/5208 (BATCH SY)

Specimen ID		Column Length mm	in.	σ Buckling MPa	ksi	Column Length mm	in.	σ Buckling MPa	ksi
1SY1424	A-1	40.79	1.606	112	16.3	20.04	0.789	376	54.6
	A-12			112	16.3			370	53.6
2SY1424	A-11			108	15.6			365	52.9
	A-12			112	16.2			371	53.8
	B-31			107	15.5			376	54.5
	B-33			108	15.7			352	51.1
	B-36			112	16.2			370	53.6
	B-46			105	15.3			356	51.7
	B-53			111	16.1			365	53.0
	B-59			113	16.4			361	52.3
1SY1424	A-8	32.41	1.276	163	23.6	14.50	0.571	465	67.5
	A-10			165	24.0			483	70.0
	A-15			166	24.1			417	60.5
	A-17			164	23.8			420	60.9
2SY1424	A-18			163	23.7			501	72.6
	A-27			155	22.5			492	71.3
	A-28			164	23.8			458	66.5
	B-41			165	24.0			491	71.2
	B-43			162	23.5			487	70.7
	B-45			165	24.0			460	66.7
1SY1424	A-9	26.87	1.058	238	34.5	8.81	0.347	496	71.9
	A-23			239	34.6			541	78.5
2SY1424	A-6			230	33.3			503	72.9
	A-17			231	33.5[a]			-	-
	A-24			232	33.7			542	78.6
	A-29			228	33.0			471	68.3
	B-42			232	33.6			465	67.4
	B-49			229	33.2			518	75.2
	B-57			232	33.6			523	75.9
	B-58			230	33.3			487	70.6

a - Specimen failed; could not be tested at shorter length

TABLE 76

COLUMN BUCKLING DATA FOR DRY LAMINATE L2, LONGITUDINAL
AT 22°C (72°F) - T300/5208 (BATCH SY)

Specimen ID		Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi
1SY1423	A-9	40.79	1.606	354	51.4	20.04	0.789	862	125.0
	A-14			356	51.7			758	109.9
	A-16			359	52.0			823	119.3
	A-19			356	51.7			778	112.8
	A-28			365	53.0			849	123.2
2SY1423	A-15			370	53.6			852	123.5
	A-27			352	51.1			854	123.9
	B-39			358	51.9			882	127.9
	B-46			349	50.6			845	122.6
	B-49			356	51.6			851	123.4
1SY1423	A-3	32.41	1.276	504	73.1	14.50	0.571	803	116.4
	A-10			488	70.8			737	106.9
	A-24			487	70.6			696	101.0
	A-27			497	72.1[a]			-	-
2SY1423	A-9			498	72.2			824	119.5
	A-25			496	72.0			831	120.5
	B-36			491	71.2			816	118.3
	B-47			495	71.8			814	118.0
	B-50			496	72.0			811	117.6
	B-52			496	72.0			856	124.2
1SY1423	A-29	26.87	1.058	591	85.7	8.81	0.347	798	115.7
2SY1423	A-16			634	92.0			788	114.3
	A-22			610	88.5[a]			-	-
	A-26			597	86.6			845	122.6
	A-29			633	91.8			842	122.1
	B-38			568	82.4[a]			-	-
	B-41			636	92.2			826	119.8
	B-44			599	86.9			816	118.4
	B-56			621	90.1			800	116.1
	B-60			574	83.3			789	114.5

a - Specimen failed; could not be tested at shorter length

TABLE 77

COLUMN BUCKLING DATA FOR DRY LAMINATE L2, TRANSVERSE
AT 22°C (72°F) - T300/5208 (BATCH SY)

Specimen	ID	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in.	σ Buckling MPa	σ Buckling ksi
1SY1423	D-1	40.79	1.606	76.5	11.1	20.04	0.789	207	30.0
	D-3			80.7	11.7			208	30.2
	D-9			81.4	11.8			209	30.3
	D-10			77.9	11.3			200	29.0
2SY1423	C-7			84.1	12.2			200	29.0
	D-18			81.4	11.8			217	31.5
	D-31			82.7	12.0			218	31.6
	E-38			80.0	11.6			210	30.5
	E-40			80.0	11.6			212	30.8
	E-50			80.0	11.6			204	29.6
1SY1423	D-6	32.41	1.276	121	19.6	14.50	0.571	211	30.6
	D-7			120	17.4			203	29.5
	D-8			119	17.3			201	29.2
2SY1423	C-3			123	17.8			200	29.0
	C-8			120	17.4			203	29.4
	C-12			118	17.1			200	29.0
	C-15			125	18.2			207	30.0
	C-16			117	17.0			211	30.6
	C-18			114	16.6			209	30.3
	D-25			121	17.5			205	29.7
2SY1423	C-5	26.87	1.058			8.81	0.347	225	32.7
	C-6							228	33.1
	C-7							212	30.7
	D-4							203	29.5
	D-9							219	31.7
	D-24			165	24.0[a]			-	-
	E-39			159	23.0			212	30.8
	E-42			169	24.5[a]			-	-
	E-47			170	24.7[a]			-	-
	E-51			167	24.2[a]			-	-
1SY1423	8-B						.347	211	30.6
2SY1423	4-C							212	30.8
	17-C							222	32.2
	35-E							210	30.5

a - Specimen failed; could not be tested at shorter length

TABLE 78

COLUMN BUCKLING DATA FOR WET LAMINATE L1, LONGITUDINAL TENSION PRECRACKED TO 80% OF σ_{ult} - T300/5208

Specimen ID	Temperature °C	°F	Column Length mm	in	σ Buckling MPa	ksi	Column Length mm	in	σ Buckling MPa	ksi
1SY-424-25A	22	72	40.79	1.606	110	15.9	20.04	0.789	361	52.3
1SY-1424-27A			40.79	1.606	114	16.6	20.04	0.789	380	55.1
2SY-1424-2A			40.79	1.606	102	14.8	20.04	0.789	363	52.6
2SY-1424-8A			32.41	1.276	153	22.2	8.81	0.347	473	68.6
2SY-1424-10A			32.41	1.276	155	22.5	8.81	0.347	494	71.7
2SY-1424-19A			32.41	1.276	165	24.0	8.81	0.347	487	70.6
2SY-1424-30A	135	275	--	--	--	--	20.04	0.789	316	45.8
2SY-1424-39B			40.79	1.606	102	14.8	20.04	0.789	331	48.0
2SY-1424-54B			40.79	1.606	103	14.9	20.04	0.789	313	45.4
2SY-1424-48B			32.41	1.276	154	22.4	8.81	0.347	389	56.4
2SY-1424-51B			32.41	1.276	148	21.5	8.81	0.347	381	55.2
2SY-1424-60B			32.41	1.276	161	23.3	8.81	0.347	328	47.6

TABLE 79

COLUMN BUCKLING DATA FOR WET LAMINATE L2, LONGITUDINAL TENSION PRECRACKED TO 80% & 90% of σ_{ult} - T300/5208

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in	σ Buckling MPa	σ Buckling ksi
Tension Precracked at 80% of σ_{ult}										
2SY-1423-21A	22W	72W	40.79	1.606	343	49.8	20.04	0.789	847	122.9
2SY-1423-40B			40.79	1.606	341	49.4	20.04	0.789	802	116.3
2SY-1423-55R			40.79	1.606	341	49.4	20.04	0.789	794	115.2
2SY-1423-1A			32.41	1.276	446	64.7	8.81	0.347	741	107.5
2SY-1423-28A			32.41	1.276	473	68.6	8.81	0.346	780	113.2
2SY-1423-30B			32.41	1.276	445	64.6	8.81	0.347	759	110.1
Tension Precracked at 90% of σ_{ult}										
1SY-1423-7A	134W	275W	40.79	1.606	310	44.9	--	--	--	--
1SY-1423-15A			40.79	1.606	325	47.2	20.04	0.789	563	81.6
2SY-1443-3A			--	--	--	--	20.04	0.789	629	91.2
1SY-1423-13A			32.41	1.276	425	61.6	8.81	0.347	732	106.2
1SY-1423-17A			32.41	1.276	430	62.4	8.81	0.347	688	99.8
1SY-1423-21A			32.41	1.276	392	56.8	8.81	0.347	714	103.6
2SY-1243-24A	135W	275W	40.79	1.606	325	47.2	20.04	0.789	650	94.3
2SY-1243-34B			--	--	--	--	20.04	0.789	603	87.4
2SY-1243-53B			40.79	1.606	332	48.2	20.04	0.789	691	100.2
2SY-1243-11A			--	--	--	--	8.81	0.347	786	114.0
2SY-1243-12A			32.41	1.276	447	64.8	--	--	--	--
2SY-1243-33B			--	--	--	--	8.81	0.347	821	119.1

TABLE 80

COLUMN BUCKLING DATA FOR WET LAMINATE L2, TRANSVERSE
TENSION PRECRACKED TO 80% OF σ_{ult} - T300/5208

Specimen ID	Temperature °C	Temperature °F	Column Length mm	Column Length in	σ Buckling MPa	σ Buckling ksi	Column Length mm	Column Length in	σ Buckling MPa	σ Buckling ksi
1SY-1423-7B	22	72	40.79	1.606	78	11.3	20.04	0.789	208	30.2
1SY-1423-1C			40.79	1.606	80	11.6	20.04	0.789	203	29.4
1SY-1423-10C			40.79	1.606	82	11.9	20.04	0.789	205	29.8
1SY-1423-10D			32.41	1.276	120	17.4	8.81	0.347	208	30.2
2SY-1423-21D			32.41	1.276	114	16.5	8.81	0.347	209	30.3
2SY-1423-27D			32.41	1.276	116	16.8	8.81	0.347	203	29.4
2SY-1423-14C	135	275	40.79	1.606	6.8	9.8	20.04	0.789	156	22.6
2SY-1423-28D			--	--	--	--	20.04	0.789	164	23.8
2SY-1423-29D			--	--	--	--	20.04	0.789	154	22.3
2SY-1423-32D			--	--	--	--	20.04	0.789	145	21.1
2SY-1423-30D			--	--	--	--	8.81	0.347	163	23.7
2SY-1423-33D			--	--	--	--	8.81	0.347	153	22.2
2SY-1423-41E			--	--	--	--	8.81	0.347	161	23.3

5. ANALYTICAL PREDICTION OF COLUMN TEST RESULTS

5.1 Previous Theoretical Development

In the elementary bending and buckling theories of beams, plates, and columns, it is assumed that the cross-sectional planes remain plane and perpendicular to the middle-surface during bending. These assumptions provide a useful approximation in the bending analysis of isotropic metals of certain geometries. In general, when a column is subjected to axial compression, cross-sections must resist shear forces and bending moments as well as the compression forces. The shear stress which results when bowing occurs produces shear strain and causes additional deflection over that due to bending. Moreover, the distribution of transverse shear stress over the cross-section is parabolic, having a maximum value at the middle and dropping to zero at the outer surfaces. The resultant variation in shear strain causes originally plane sections to warp out of the plane. If the shear rigidity is too low, the assumptions of elementary theory no longer provide a suitable approximation, and the value of compressive load at which buckling occurs is lower than that calculated from elementary considerations.

As an example, consider the problem of a pin-ended column under compressive force. The equation for the buckling load, taking into account the effect of transverse shear deformation, can be derived as below (see Reference 8 Eq. (2-57), p. 133, for the derivation in a similar case);

$$F_{cr} = \frac{\pi^2 EI/L^2}{1 + \frac{\pi^2 EI}{L^2}\frac{1}{S}} = \frac{P_E}{1 + P_E/S} \qquad (1)$$

where S is a shear stiffness parameter, in the same sense that the Euler load P_E is a measure of bending stiffness. In arriving at this result, for

simplicity, the assumption that plane sections remain plane is retained but the assumption that these sections remain perpendicular to the column axis is not. From this simple equation we can see the following:

(a) When $SL^2/\pi^2 EI \to \infty$, i.e., either S is large or L is large or both, and EI remains finite, $P_{cr} \to P_E$. This is the case of classical buckling of a solid column of metal.

(b) If $\pi^2 EI/L^2 \to \infty$, i.e., either $EI \to \infty$ or $L \to 0$, and S remains finite, $P_{cr} \to S$. This is the case of pure shear failure, such as may sometimes occur in a wooden column by splitting.

(c) When S is finite, we always get a reduction in P_{cr}. The smaller the value of S, the smaller is P_{cr}. This corresponds to our present case of buckling of anisotropic laminated columns in which the transverse shear moduli are low.

Previous, umpublished work based on these consideration has established a method of analysis for buckling of a specially orthotropic beam-column (or plate), which takes into account the effect of transverse shear deformations. This development was utilized in the present program. The derivation is based on the following constitutive relations:

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{yz} \\ \tau_{zx} \\ \tau_{xy} \end{bmatrix} = \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & 0 & 0 & 0 \\ \bar{Q}_{12} & \bar{Q}_{22} & 0 & 0 & 0 \\ 0 & 0 & \bar{Q}_{44} & 0 & 0 \\ 0 & 0 & 0 & \bar{Q}_{55} & 0 \\ 0 & 0 & 0 & 0 & \bar{Q}_{66} \end{bmatrix} \begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_{yz} \\ \epsilon_{zx} \\ \epsilon_{xy} \end{bmatrix} \tag{2}$$

It is assumed that the transverse shear stresses of each lamina are related to the transverse stiffnesses, to functions characterizing a parabolic distribution over the cross-section, and to arbitrary undetermined functions of the x and y coordinates $\phi(x, y)$ and $\psi(x, y)$ respectively. Also, the cross-coupling stiffnesses can be taken to be zero, since the laminate is pseudo-homogeneous. The equations of equilibrium for a multi-layer anisotropic plate are then expressed in a manner which parallels that of Ambartsumyan in Reference 10, but

generalized for the case of an even or an odd number of laminae of balanced layup, by summing up normal and transverse stiffness contributions of the individual laminae under the requirements of compatibility and equilibrium. Under these assumptions the following governing differential relations are then derived:

$$K_{55} \frac{\partial \phi}{\partial x} + K_{44} \frac{\partial \psi}{\partial y} - N_x \left(\frac{\partial^2 w}{\partial x^2} + \alpha \frac{\partial^2 w}{\partial y^2} \right) = 0$$

$$\begin{aligned} & D_{11} \frac{\partial^3 w}{\partial x^3} + (D_{12} + 2D_{66}) \frac{\partial^3 w}{\partial x \partial y^2} - (F_{11} + H_{115}) \frac{\partial^2 \phi}{\partial x^2} \\ & - (F_{66} + H_{665}) \frac{\partial^2 \phi}{\partial y^2} - (F_{12} + F_{66} + H_{124} + H_{664}) \frac{\partial^2 \psi}{\partial x \partial y} \\ & + K_{55} \phi = 0 \end{aligned} \tag{3}$$

$$\begin{aligned} & D_{22} \frac{\partial^3 w}{\partial y^3} + (D_{12} + 2D_{66}) \frac{\partial^3 w}{\partial x^2 \partial y} - (F_{22} + H_{224}) \frac{\partial^2 \psi}{\partial y^2} \\ & - (F_{66} + H_{664}) \frac{\partial^2 \psi}{\partial x^2} - (F_{12} + F_{66} + F_{125} + H_{665}) \frac{\partial^2 \phi}{\partial x \partial y} \\ & + K_{44} \psi = 0 \end{aligned}$$

This result is similar to Equations (10.25) - (10.27) in Chapter II of Reference 10, except for somewhat greater generality and ease of implementation; in addition, it is written in terms of the lamina stiffnesses with respect to lamination axes, and, therefore, provides for cross-ply laminae whose orthotropic axes do not coincide with the lamination axes.

The theoretical development expressing the bending stiffness of the multiply laminate incorporating transverse shear deformations is equivalent to that presented by Whitney in Reference 11, when the cross-coupling stiffnesses Q_{45} and a_{45} are taken equal to zero, although formulated in a slightly different fashion. This theory accomplishes for the composite laminate what Equation (1) does for an isotropic bar. However, this analysis does not require that plane sections remain either plane or normal to the middle surface.

When applied to the problem of the buckling of a plate-column with ends simply supported and unloaded edges free, the boundary conditions are:

$$\text{at } x = 0 \text{ and } L: \qquad w,\ M_x,\ \psi = 0 \tag{4}$$

To satisfy the boundary conditions, a solution is assumed in the form of a trigonometric function:

$$\begin{aligned} w &= A \sin m\pi x/L \\ \phi &= B \cos m\pi x/L \\ \psi &= C \sin m\pi x/L \end{aligned} \tag{5}$$

Substitution of these relations into the general equations provides two simultaneous homogeneous equations. The buckling load solution in closed form is obtained by the vanishing of the determinant, and the result is rewritten here as follows:

$$(N_x)_{cr} = \frac{\pi^2 D_{11}}{L^2} \cdot \left[\frac{K_{55}}{\frac{\pi^2}{L^2}(F_{11} + H_{115}) + K_{55}} \right] \tag{6}$$

where

$$D_{11} = \sum_{k=1}^{n} \frac{1}{3} \bar{Q}_{11}^{(k)} (h_k^3 - h_{k-1}^3) \tag{7}$$

$$K_{55} = \sum_{k=1}^{n} \left\{ \frac{1}{2} \bar{Q}_{55}^{(k)} \left[\frac{h^2(h_k - h_{k-1})}{4} - \frac{h_k^5 - h_{k-1}^5}{3} \right] \right.$$

$$\left. + a_{55}^{(k)}(h_k - h_{k-1}) \right\} \tag{8}$$

$$F_{11} = \sum_{k-1}^{n} \frac{1}{6} \bar{Q}_{11}^{(k)} \left[\frac{h^2(h_k^3 - h_{k-1}^3)}{4} - \frac{h_k^5 - h_{k-1}^5}{5} \right] \tag{9}$$

$$H_{115} = \sum_{k=1}^{n} \bar{Q}_{11}^{(k)} \left[\frac{1}{3} \frac{a_{55}^{(k)}}{\bar{Q}_{55}^{(k)}} (h_k^3 - h_{k-1}^3) + \frac{1}{2} b_{55}^{(k)} (h_k^2 - h_{k-1}^2) \right] \tag{10}$$

In Equations (7) to (10), $\bar{Q}_{11}^{(k)}$ and $\bar{Q}_{55}^{(k)}$ are the moduli of the k^{th} lamina transformed to the laminate axes, as defined in Reference 12, $h^{(k)}$ is the distance from the neutral plane to the interface between the laminae k-1 and k, and $a_{55}^{(k)}$ and $b_{55}^{(k)}$ identify the proportionate shear stiffness contributions of the k^{th} lamina.

The analogy between Equations (1) and (6) is immediately apparent if the latter is written in the form:

$$(N_x)_{cr} = (N_x)_E \,/\, [1 + (N_x)_E/S_p] \tag{11}$$

where:

$$(N_x)_E = \pi^2 D_{11}/L^2 \tag{12}$$

$$S_p = K_{55}D_{11}/(F_{11} + H_{115}) \tag{13}$$

The solution of Equation (6) has been programmed for digital computation, for which the following input data are required:

Laminate (layup) geometry and details

Lamina stiffnesses E_{1c}, E_{2c}, ν_{12}, G_{12}, G_{13}, G_{23}

Pin-end length

5.2 Application to Column Buckling Test Data

In the application of the analysis described above to the column tests of this report, two problems arise:

(1) Values of the lamina shear stiffnesses G_{13} and G_{23}, required as input data, are not available by direct experiment.

(2) When values of G_{13} and G_{23} are assumed which are in accordance with micromechanics analysis or ultrasonic test data (as, for example, Reference 13), the column analysis consistently predicts buckling stresses higher than test values.

There are several possible explanations for the difficulty cited in Item 2, for example:

(1) The shear stress-strain relation for graphite/epoxy composite is quite non-linear. Consequently, ultrasonic tests, which are performed at relatively low stress levels, are undoubtedly associated with higher values of the tangent modulus to the stress-strain curve than are mechanical buckling tests.

(2) Non-linearity of the shear stress-strain curve is accompanied by plastic deformation. The combined stress condition in a column test specimen would advance plastic flow, and a reduction in the apparent tangent shear modulus should be expected. In metals such effects have been successfully predicted by application of the Mises-Hencky shear strain energy theory of failure, for example.

(3) The theory behind Equation (6) is based on simplified approximations which represent lamina stresses by their average values and ignore interply reactions known to occur at the edges. Moreover, the theory does not account for the possiblity of anticlastic bending (i.e., edge-to-edge saddle-shaped bowing), which, if not restrained, might result in reduced stiffness, especially for cross-ply laminates.

(4) Small variations in fiber distribution and in thickness tend to result in inherent eccentricities for in-plane loads. As in isotropic materials, eccentricity reduces the strength of short columns below the compression ultimate through beam-column action. Additionally, the shear modulus effective at the critical load is the tangent to the shear stress-strain curve at some finite value of shear, which in graphite-epoxy is likely to be significantly less than the initial modulus.

Because of these recognized limitations, a type of trial-and-error approach was used whereby lamina shear stiffnesses of the composite material were selected to obtain good agreement between the column analysis predictions and the experimental data for the room temperature tests on unidirectional and angle-plied laminates. These selected shear stiffness values are designated G'_{13} and G'_{23}. Other elastic constants used in the analysis are selected as representative of the material behavior in the stress range of interest, based on the stress-strain data presented in Section 4. These properties are listed in Table 81.

Initial trial values of G'_{13} were guided by the results of previous unpublished studies in which 45 three-point bending tests were made on 22 different (0_{16}) T300/5208 flexure specimens at three different length-to-thickness ratios. In reducing these data, a relaxation analysis was used to compute beam deformation as the sum of that due to exact bending stress distribution and that due to exact shear stress distribution, taking account of the usually ignored Saint-Venant effects of concentrated load and overhang. Averaged test results for each of the three test spans furnished deformation data with a coefficient of variation of 0.02; only two sets of data were required to establish the unknown values of E_{11} (mean) and G'_{13} (the effective shear modulus for this case); consequently one data set was redundant. The values of E_{11} = 140.7 GPa (20.4 msi) and G'_{13} = 7.76 GPa (400 ksi) agreed with all three data sets to within 0.5 percent.

In fitting the column analysis to the experimental data of this report, good correlation was obtained with the values G'_{13} = 2.10 GPa (300 ksi) and G'_{23} = 310 MPa (45 ksi), for T300/5208 material at room temperature. The comparison was then extended to other temperature conditions by modifying the

TABLE 81. SUMMARY OF ELASTIC PROPERTIES USED IN COLUMN ANALYSIS

Material	Laminate [a]	Condition	Temperature		Based on Direct Tests							Indirect				Basis
					E_{1C}		E_{2C}		ν_{12}	G_{12}		G'_{13}		G'_{23}		
			°C	°F	GPa	$\times 10^6$ psi	GPa	$\times 10^6$ psi		GPa	$\times 10^6$ psi	GPa	ksi	MPa	ksi	
T300/ 5208	U1 L1 L2	Dry & Wet	22°	72°	130	19.0	10.3	1.50	0.27	5.2	0.75	2.1	300	310	45	(1)
T300/ 5208	U1 L1 L2	Dry & Wet	-54°	-65°	130	19.0	10.3	1.50	0.27	5.6	0.81	2.2	320	340	50	(2)
T300/ 5208	U1 L1 L2	Dry & Wet	93°	200°	130	19.0	8.3	1.20	0.27	4.5	0.66	1.8	260	280	40	(2)
T300/ 5208	U1 L1 L2	Dry & Wet	135°	275°	130	19.0	8.3	1.20	0.27	4.5	0.66	1.8	260	280	40	(2)
AS/3501-5A	U1 L1 L2	Dry	22°	72°	130	19.0	10.3	1.50	0.27	5.2	0.75	2.1	300	310	45	(3)
AS/3501-5A	U1 L1 L2	Wet	135°	275°	130	19.0	6.2	0.90	0.27	3.5	0.50	1.4	200	210	30	(2)

(1) Selected for best fit of laminates L1L, L1T, L2L, and L2T.

(2) G'_{13} and G'_{23} were derived from values at RT in the same ratio as found for in-plane shear modulus G_{12}.

(3) Elastic constants were assumed identical to those of T300/5208 at room temperature.

values of G'_{13} and G'_{23} in the same ratio as the change in G_{12}, determined by test data reported in Section 4.5. These relations are summarized in Table 81. In this manner, a consistent set of values for G'_{13} and G'_{23} was derived for all the various test conditions.

This analysis was repeated for laminates of AS/3501-5A material. Values of G'_{13} and G'_{23} for AS/3501-5A at room temperature dry were chosen to be the same as for T300/5208. G'_{13} and G'_{23} for AS/3501-5A at 275°F wet were modified in a fashion similar to that used for T300/5208. Good correlation was also obtained.

The resultant column curves are presented in Figures 87 through 122, together with the column test data for comparison. Except in the very short column range, where failure may be expected to be initiated by inelastic effects, good agreement is found throughout between the analytical prediction and the test result, for six different laminate geometries, four different temperatures (dry and wet), and two materials.

5.3 Predictions of Theory Using Elastic Moduli as Given in Literature

As noted previously, values of the elastic moduli E_{1c}, E_{2c}, G_{13} and G_{23} taken in accordance with ultrasonic wave propagation data and micromechanics analysis as reported in the literature do not provide good predictions of column strength when used with the analytical method of Section 5.1. The extent of the discrepancy is illustrated for representative cases (T300/5208 laminates, RT Dry) in Figures 123 - 128. Here the column test data are compared with the results of the analysis when the shear moduli are taken (a) as given in Reference 13, and (b) as assumed above in Section 5.2.

It is apparent that shear effects as predicted by the commonly assigned values of the moduli do not begin to account for the results obtained in the column tests. The sensitivity of the prediction to the values of the shear moduli alone is shown further in Figures 129 - 134, where representative solutions are presented for a range of arbitrarily selected values of G'_{13} and G'_{23}, using the extensional moduli of Table 81, and compared with the

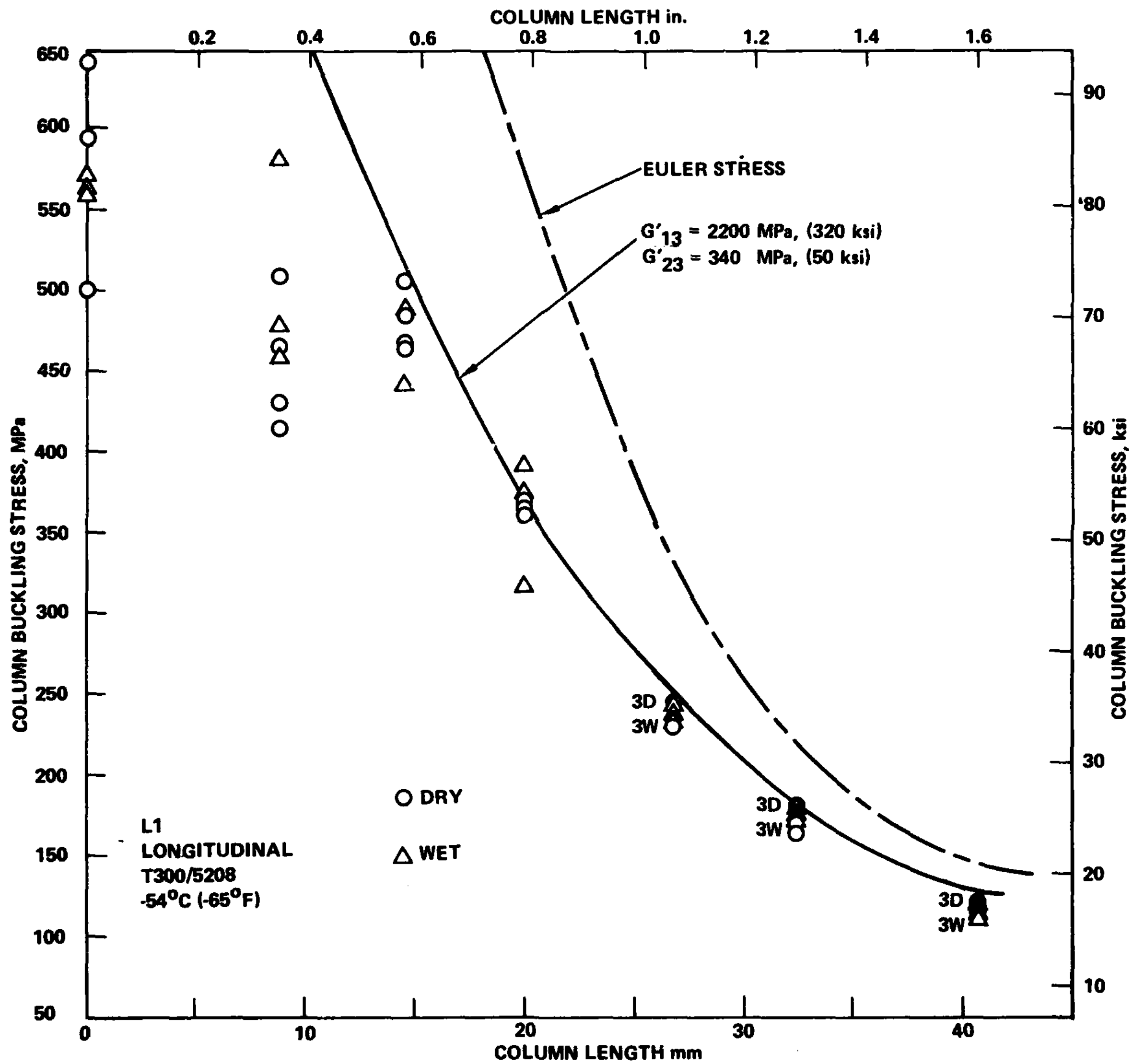

Figure 87. - Column test results at -54°C for T300/5208 quasi-isotropic laminate L1L.

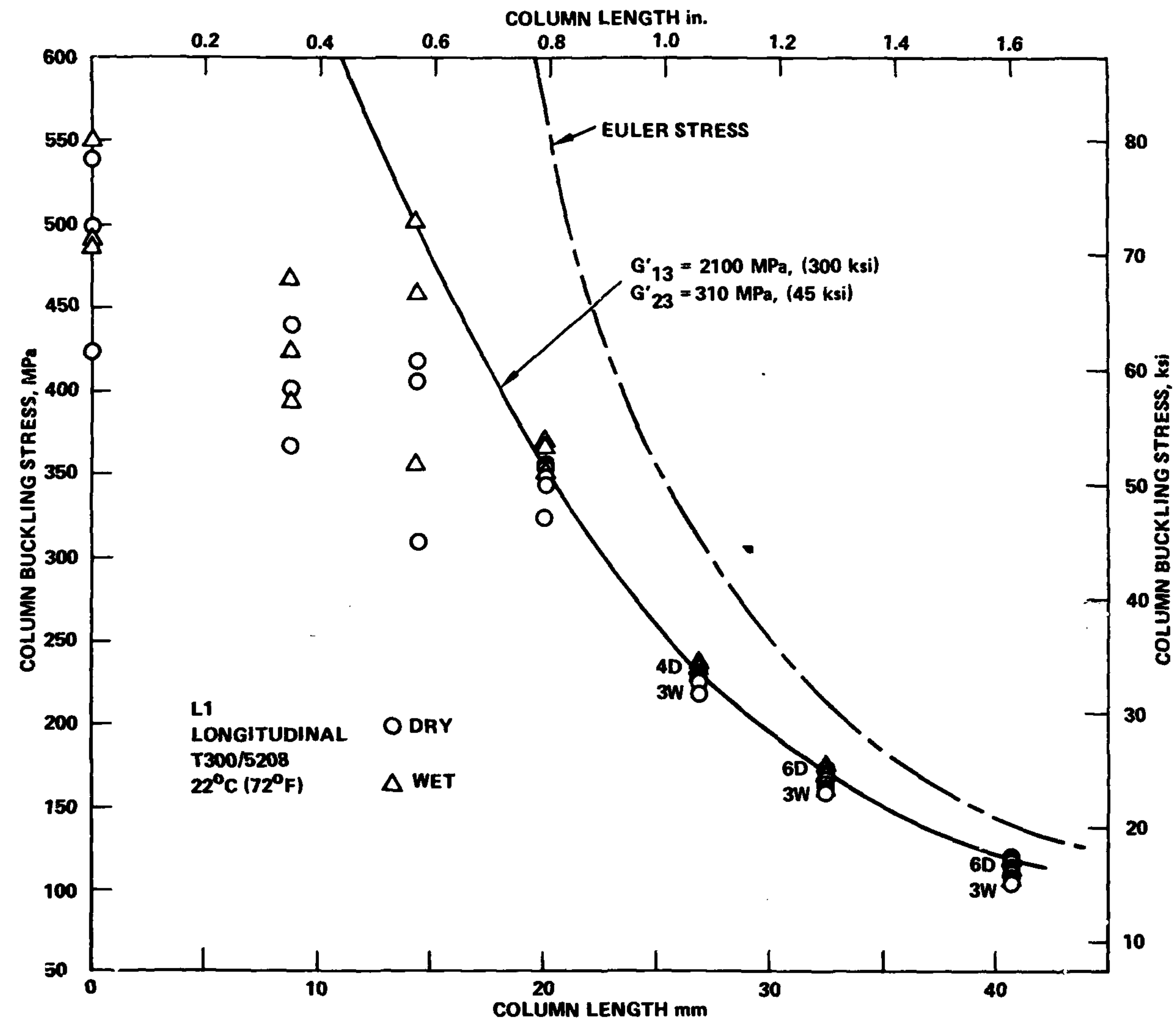

Figure 88. - Column test results at 22°C for T300/5208 quasi-isotropic laminate L1L.

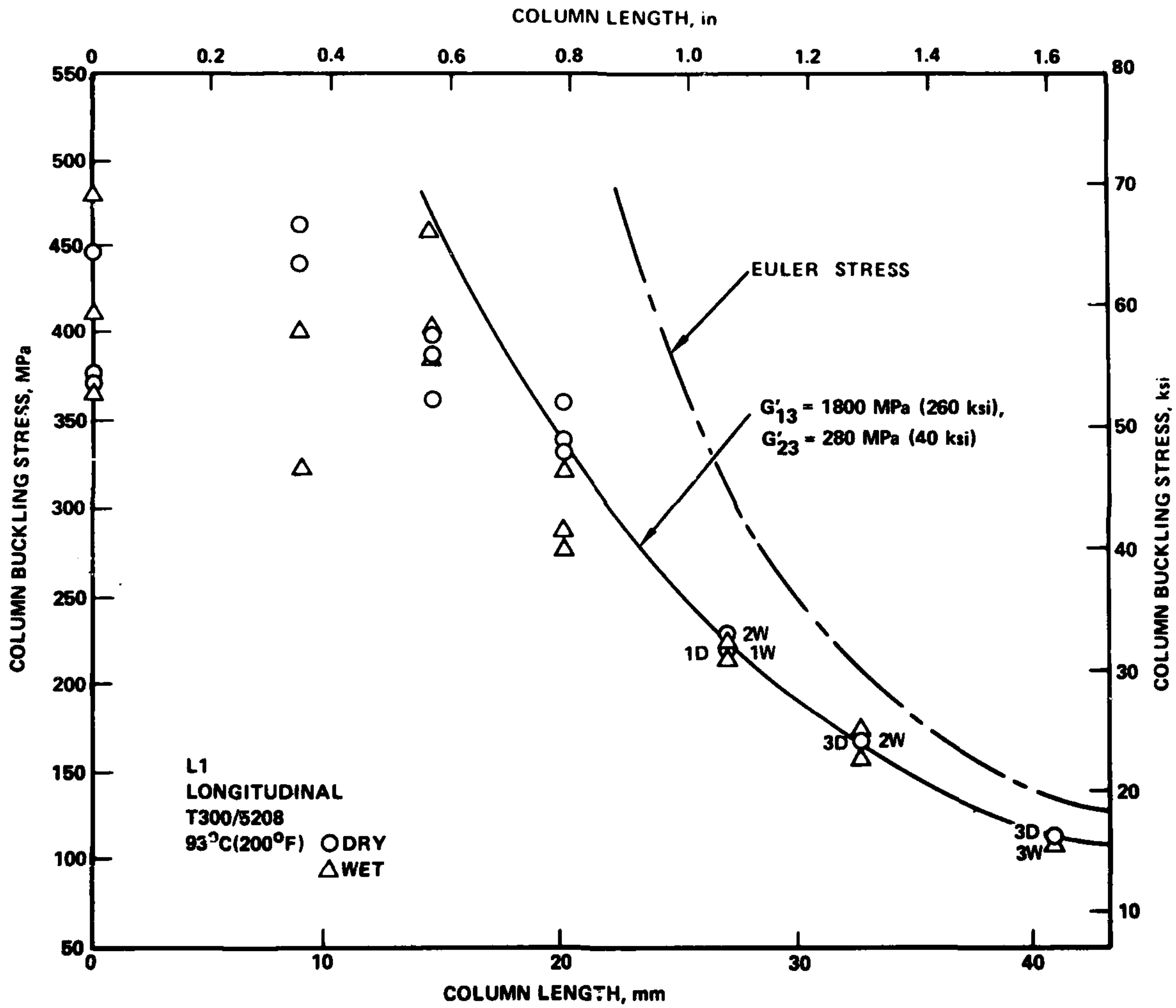

Figure 89. - Column test results at 93°C for T300/5208 quasi-isotropic laminate L1L.

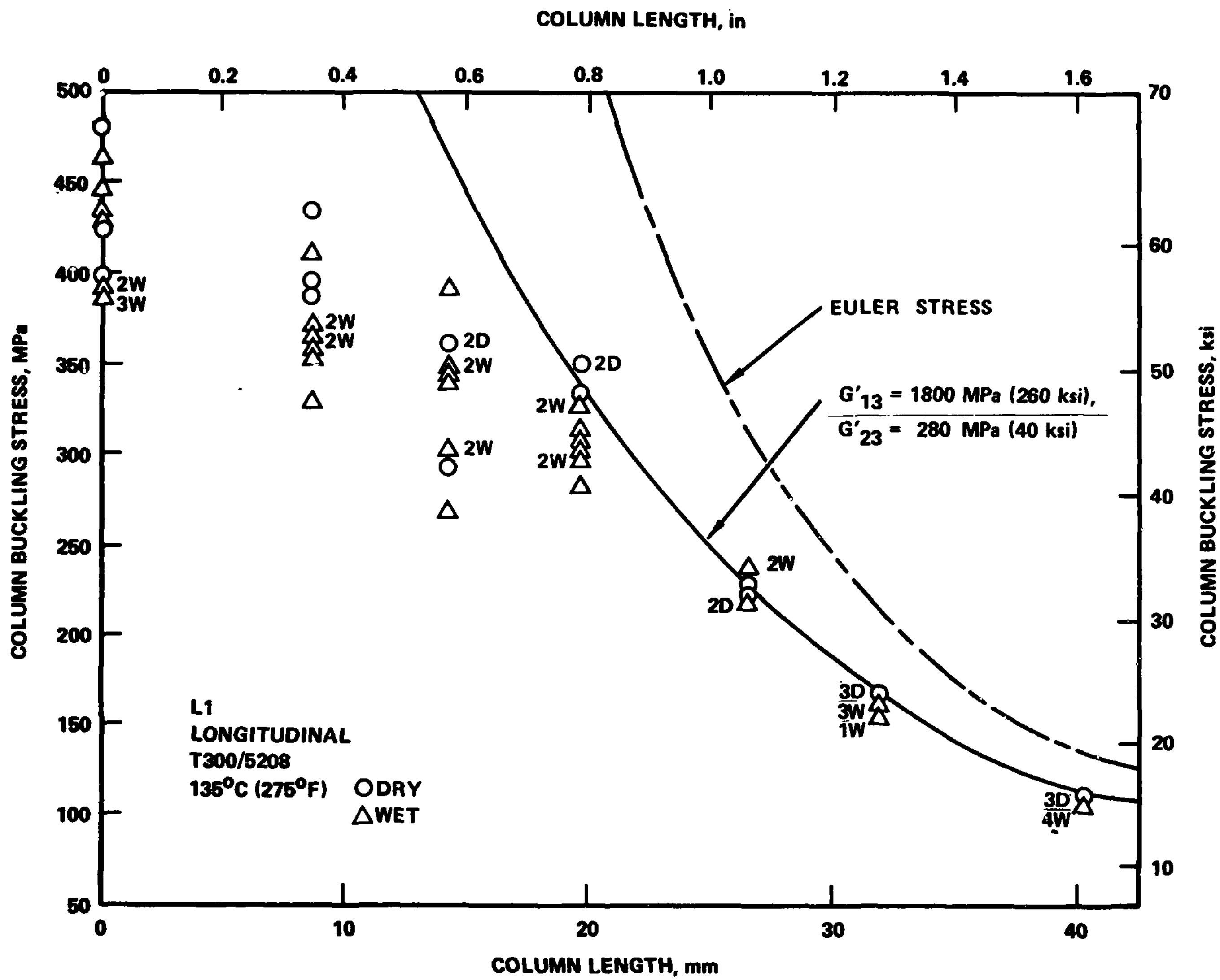

Figure 90. - Column test results at 135°C for T300/5208 quasi-iotropic laminate L1L.

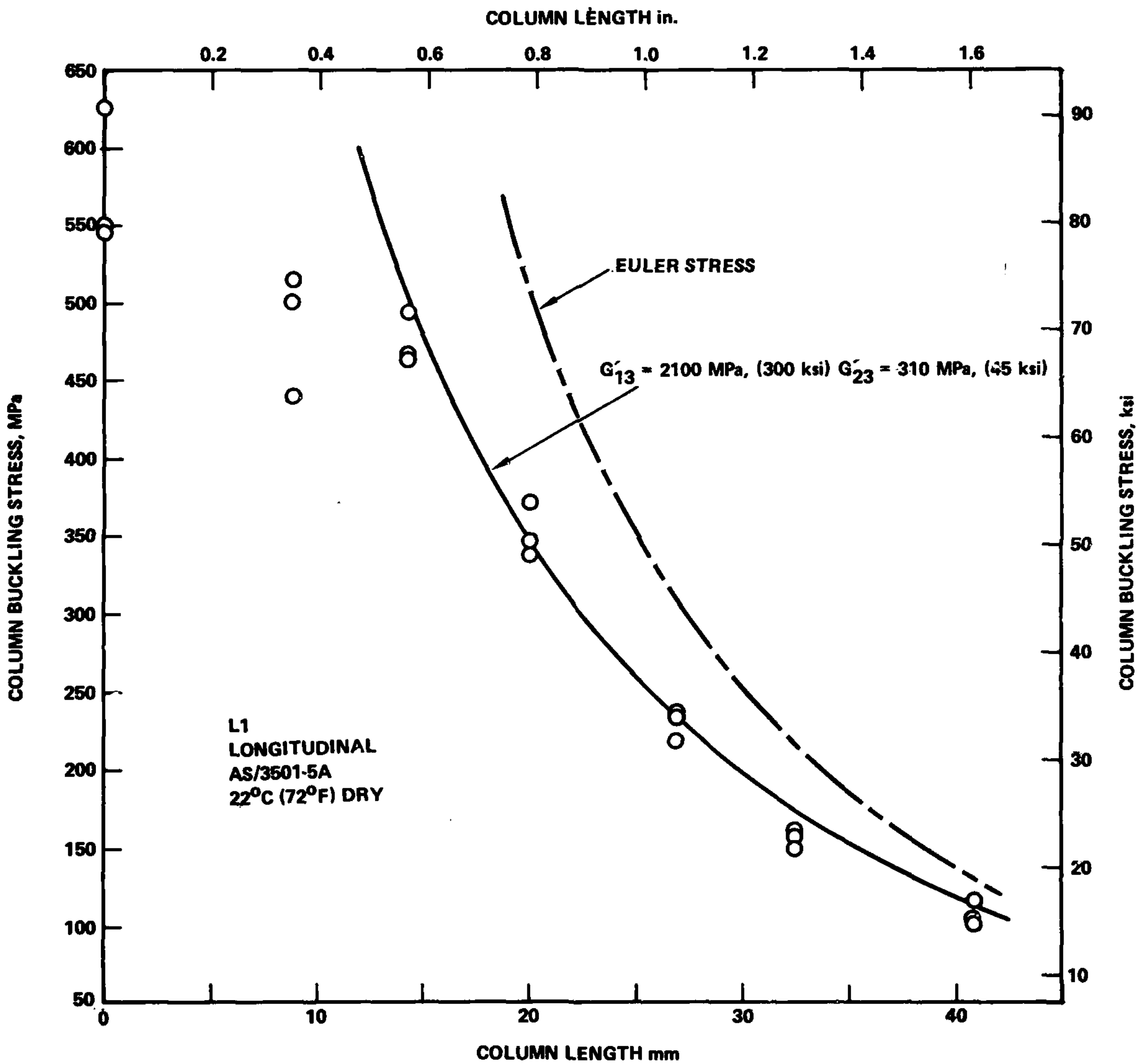

Figure 91. - Column test results at 22°C for AS/3501-5A quasi-isotropic laminate L1L.

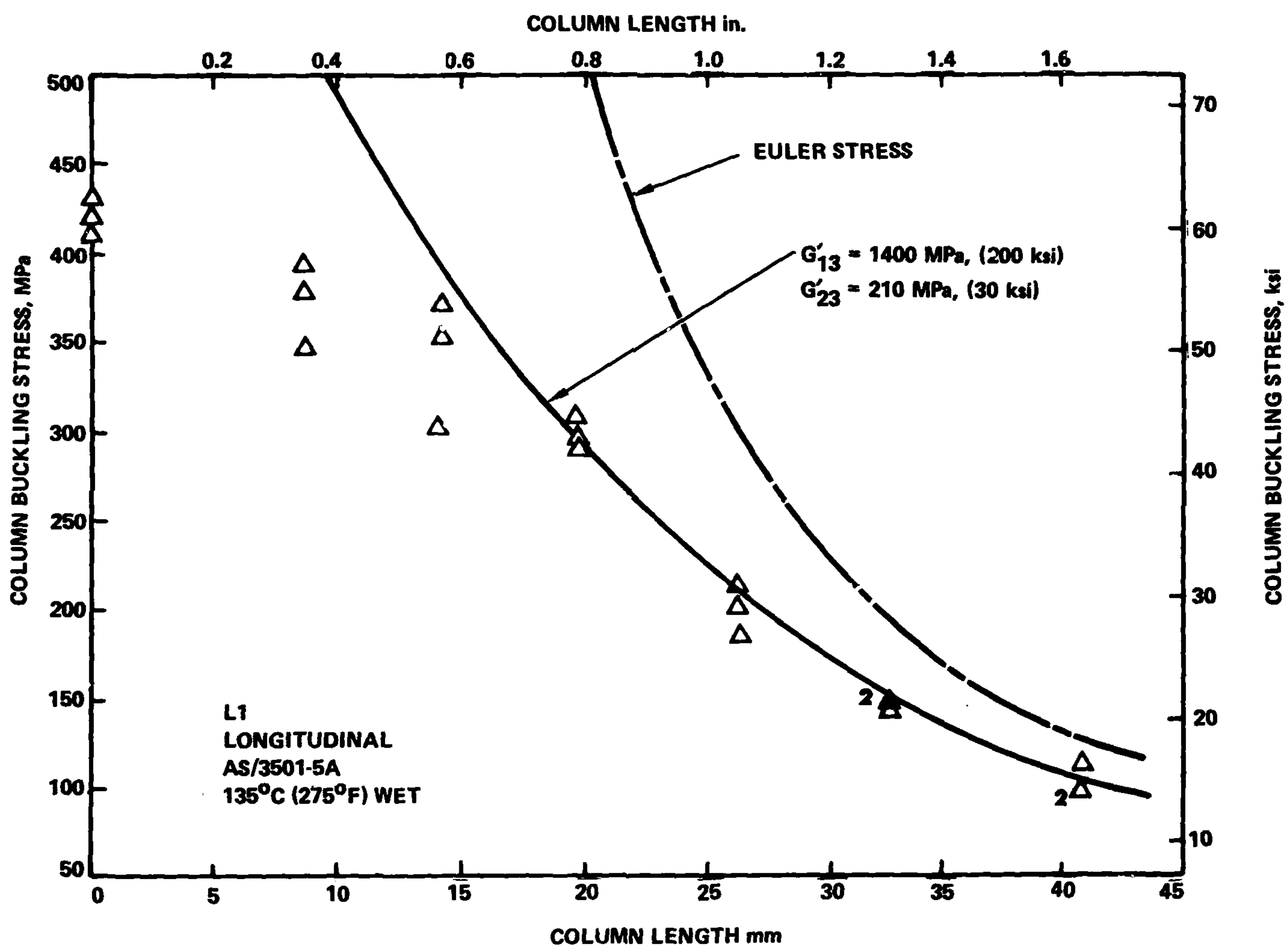

Figure 92. - Column test results at 135°C for AS/3501-5A quasi-iotropic laminate L1L.

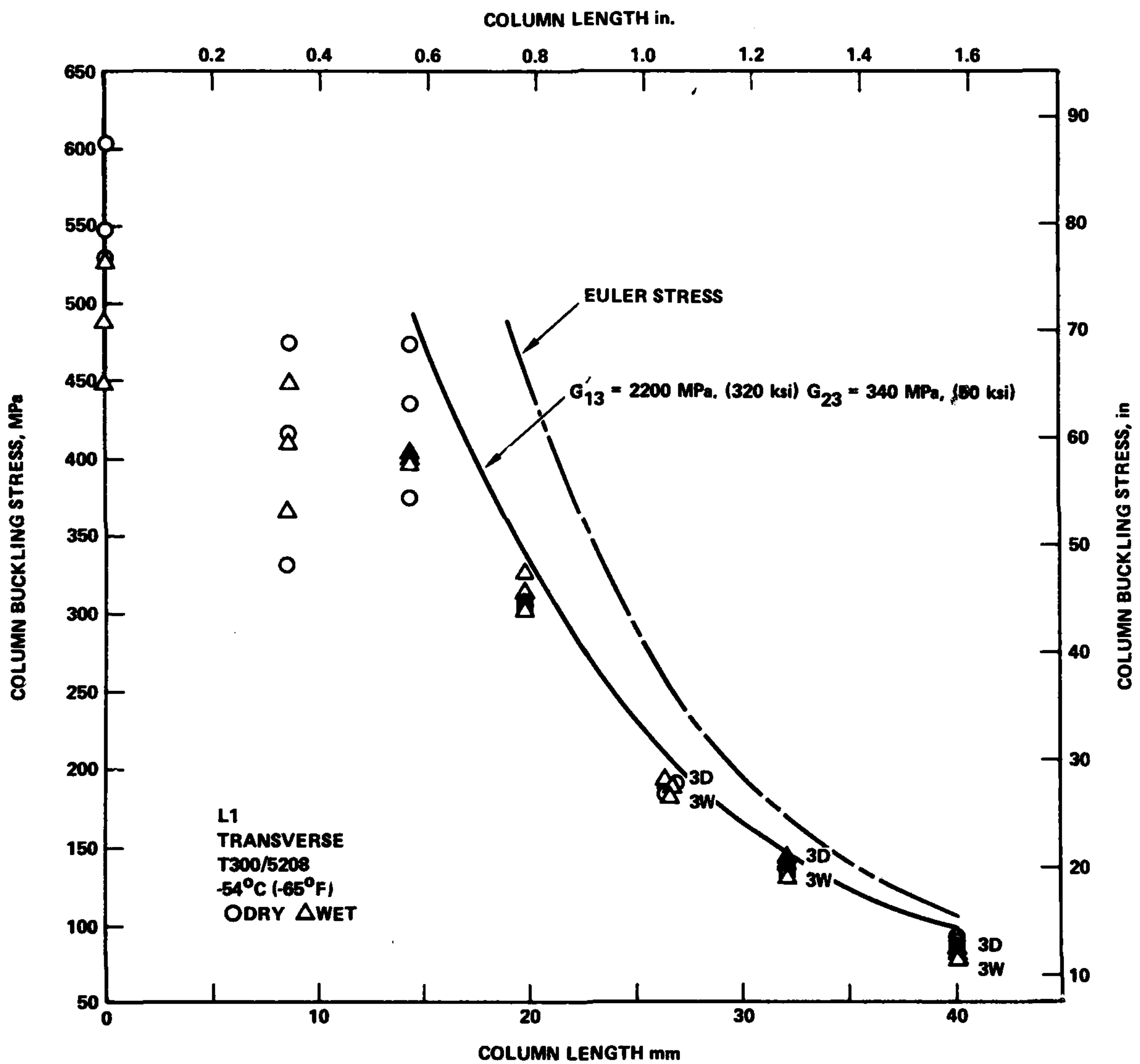

Figure 93. Column test results at -54°C for T300/5208 quasi-isotropic laminate L1T.

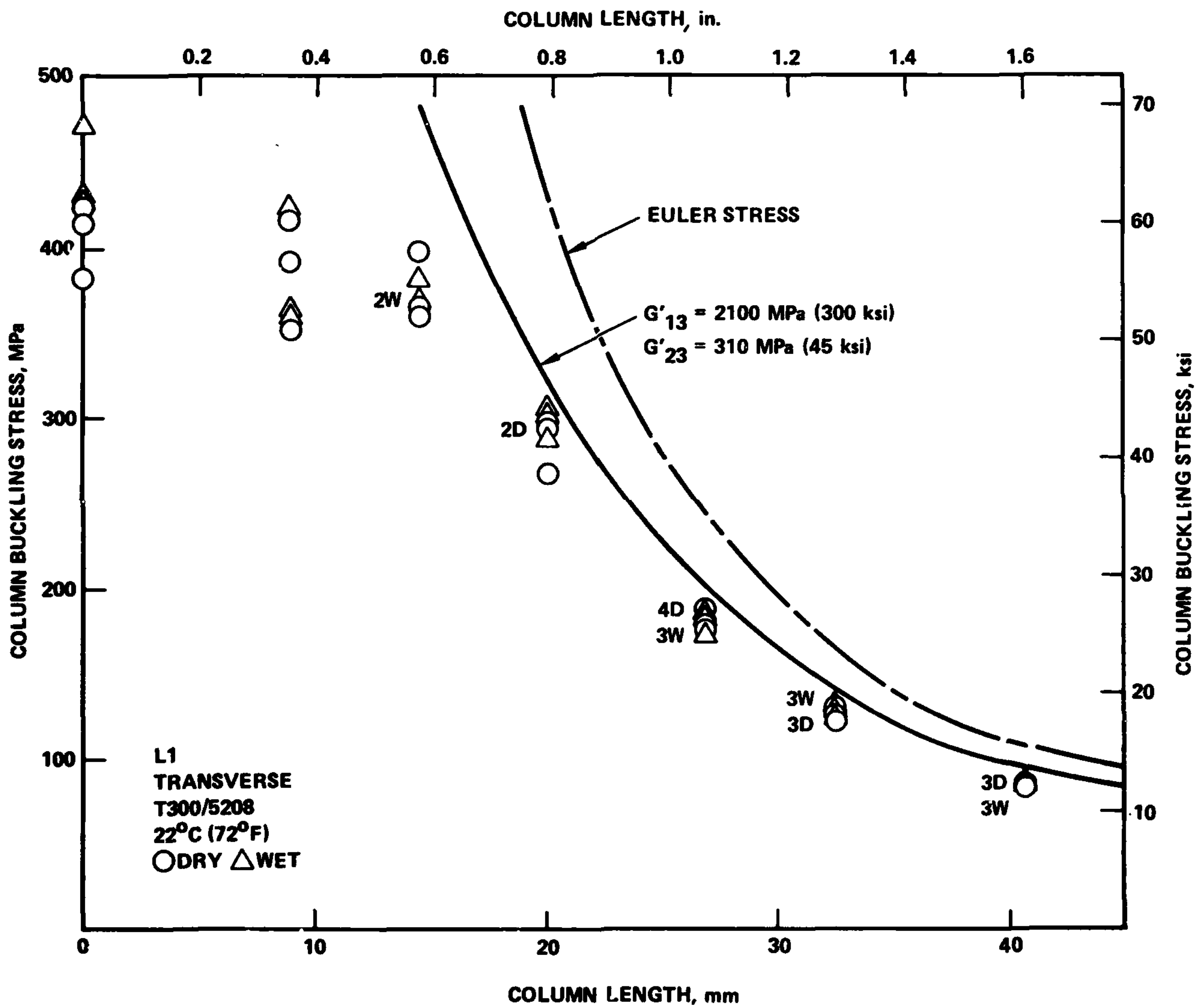

Figure 94. - Column test results at 22°C for T300/5208 quasi-isotropic laminate L1T.

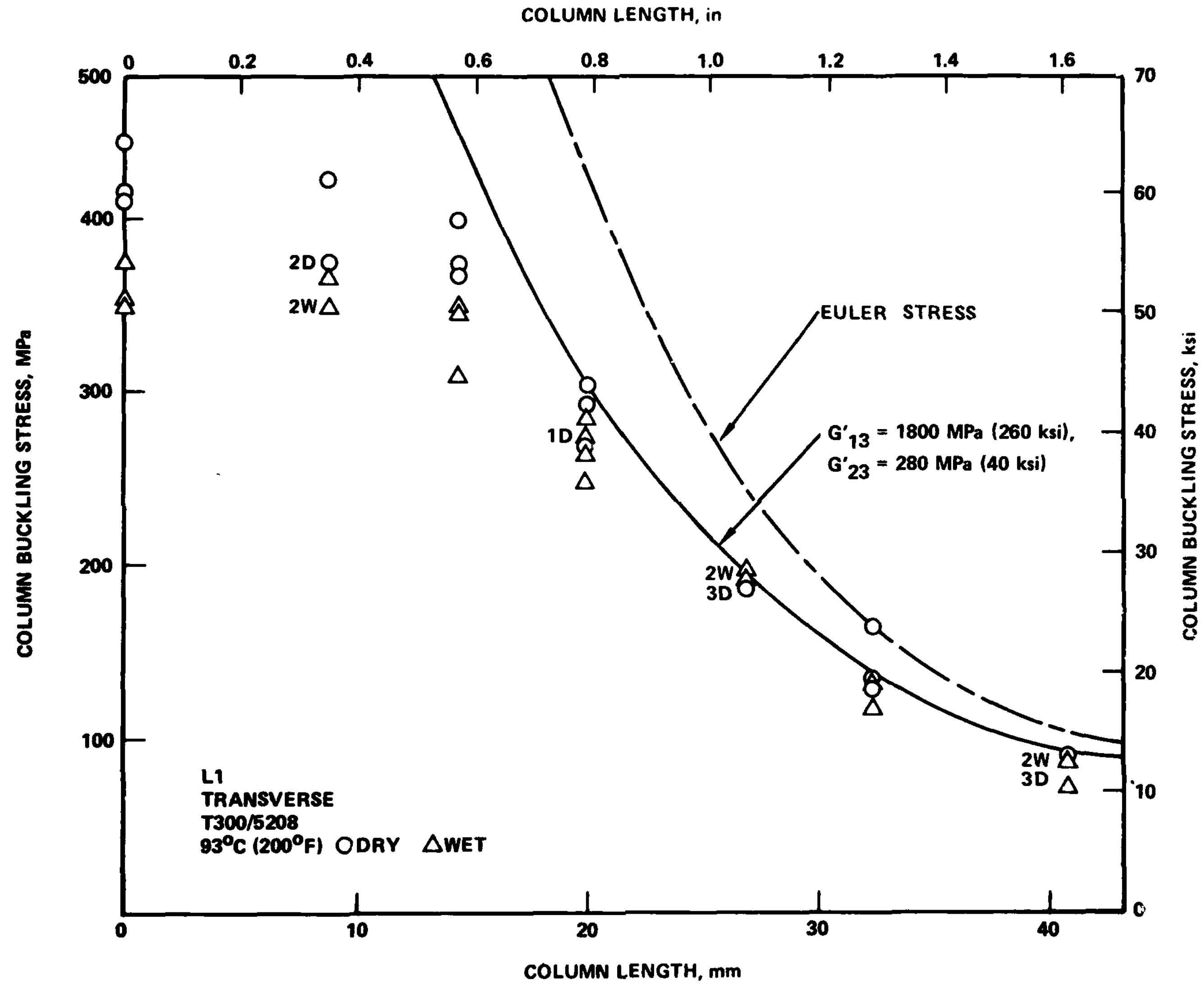

Figure 95. - Column test results at 93°C for T300/5208 quasi-isotropic laminate L1T.

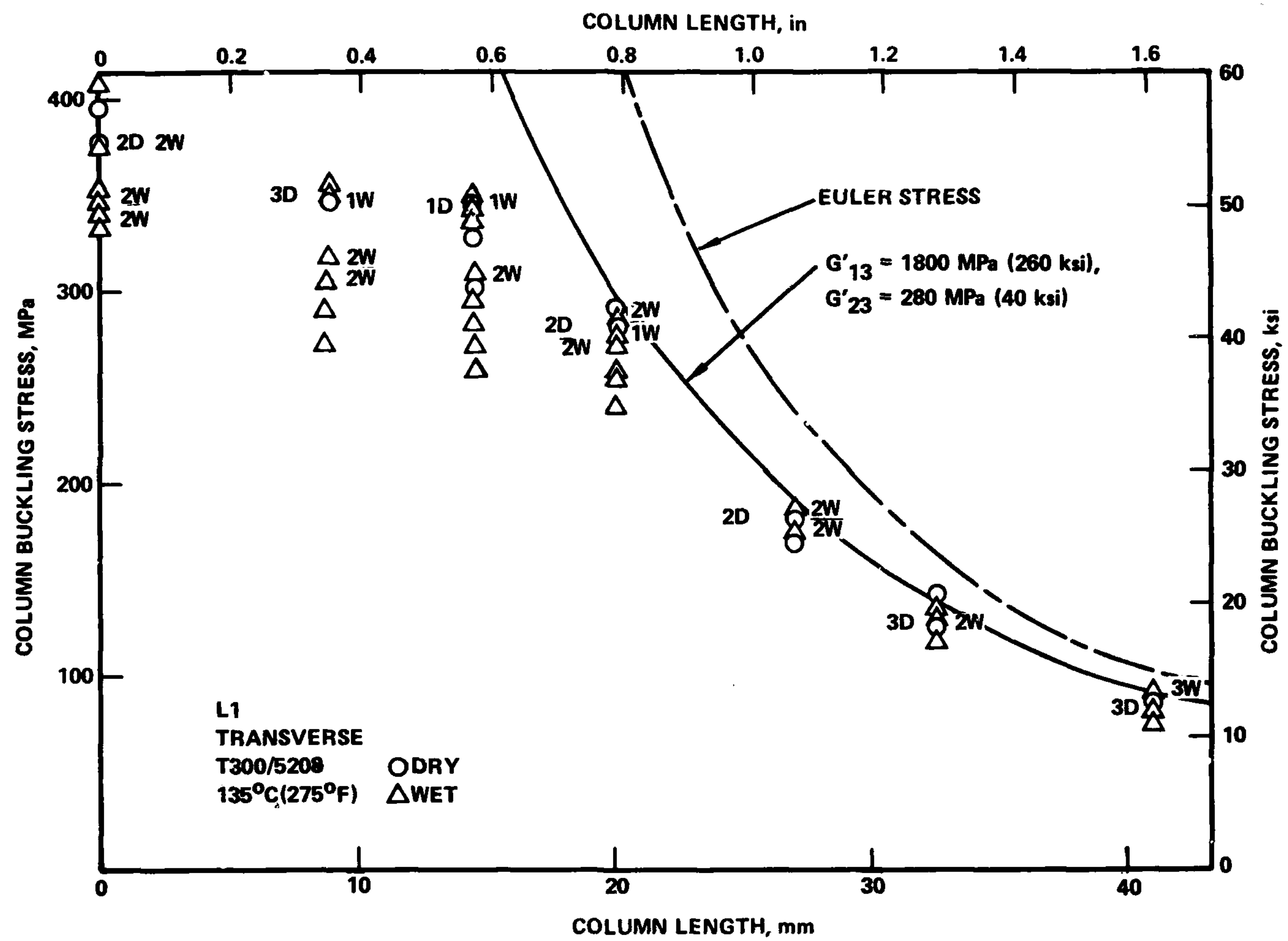

Figure 96. - Column test results at 135°C for T300/5208 quasi-isotropic laminate L1T.

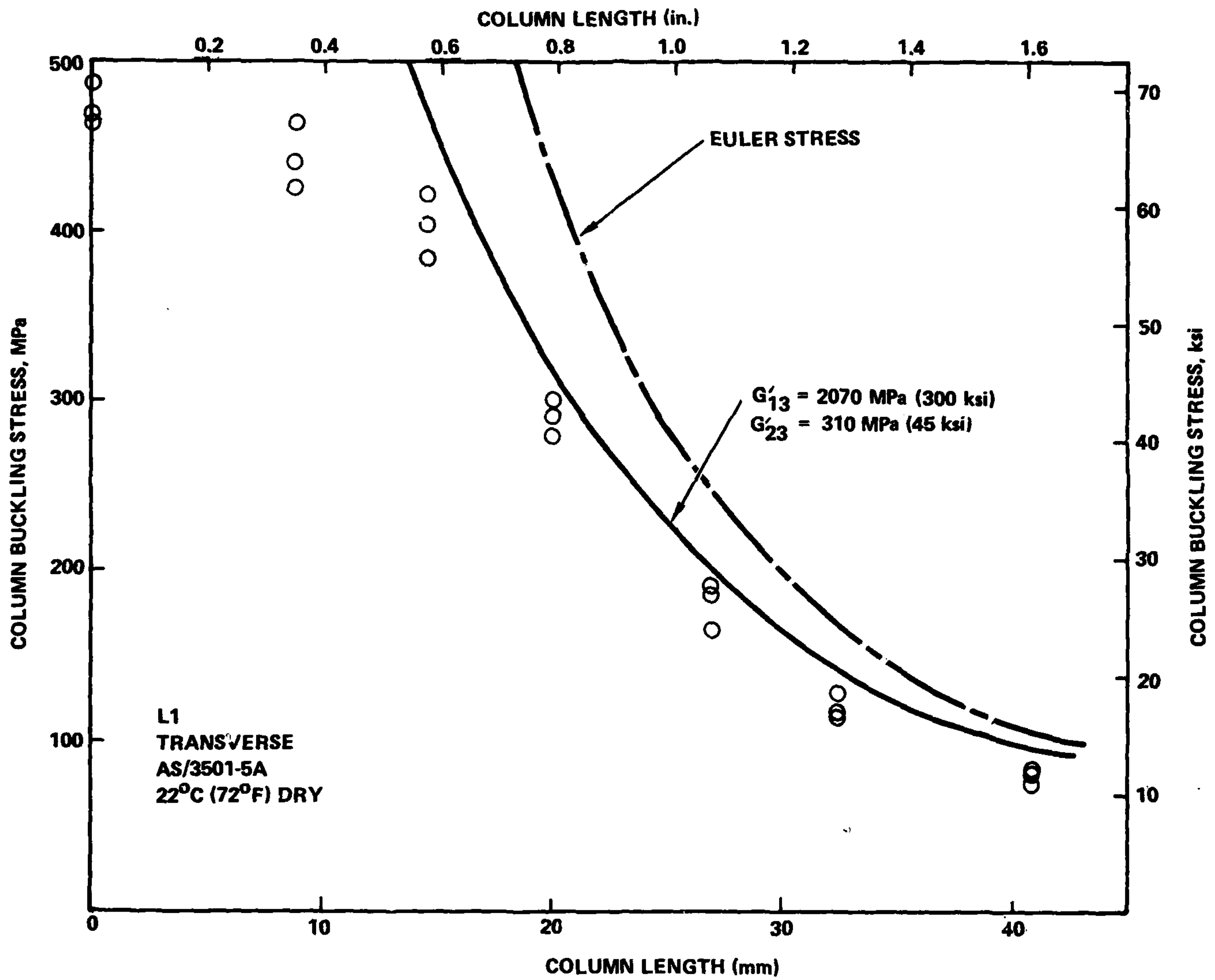

Figure 97. - Column test results at 22°C for AS/3501-5A quasi-isotropic laminate L1T.

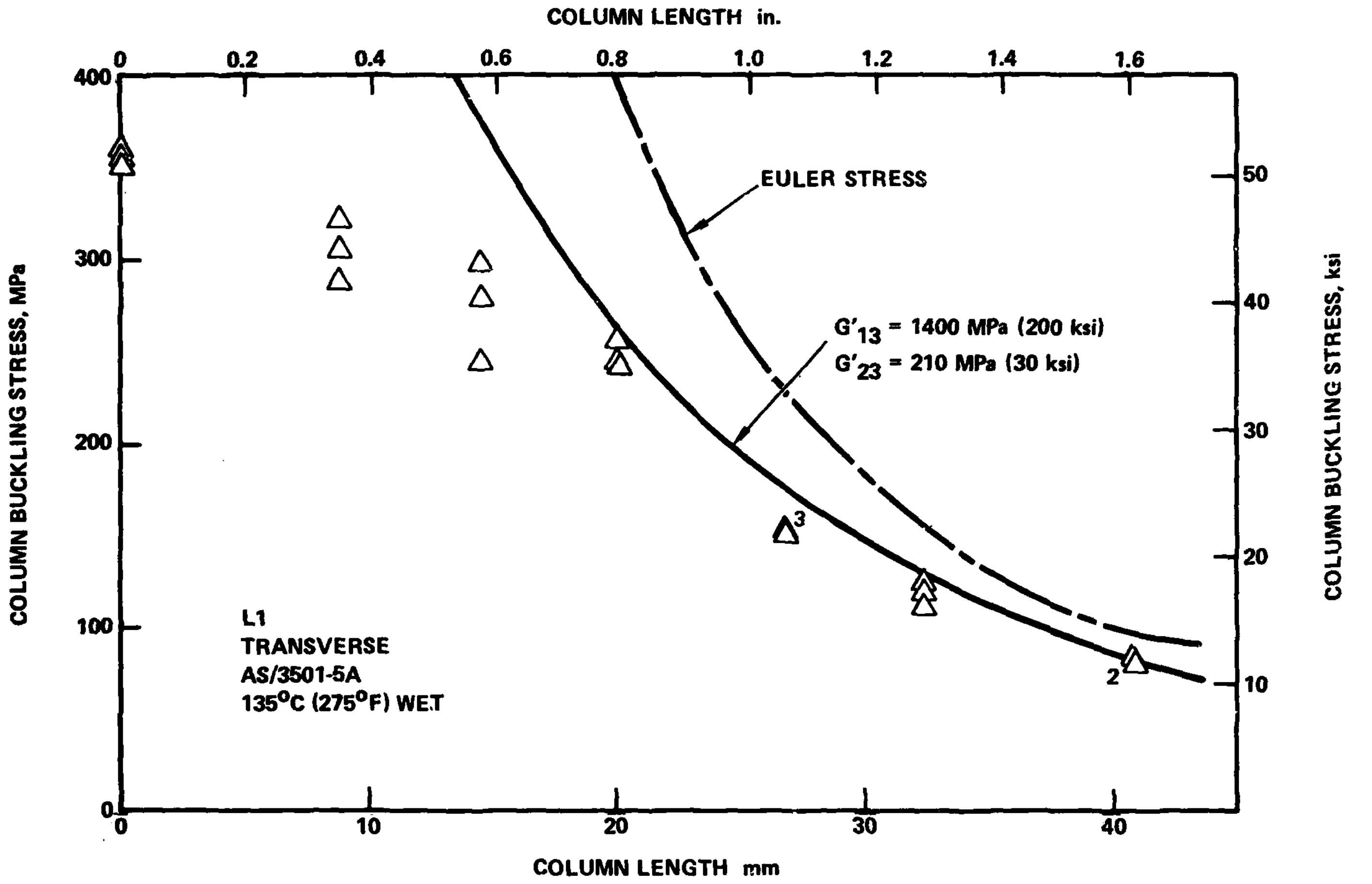

Figure 98. - Column test results at 135°C for AS/3501-5A quasi-isotropic laminate L1T.

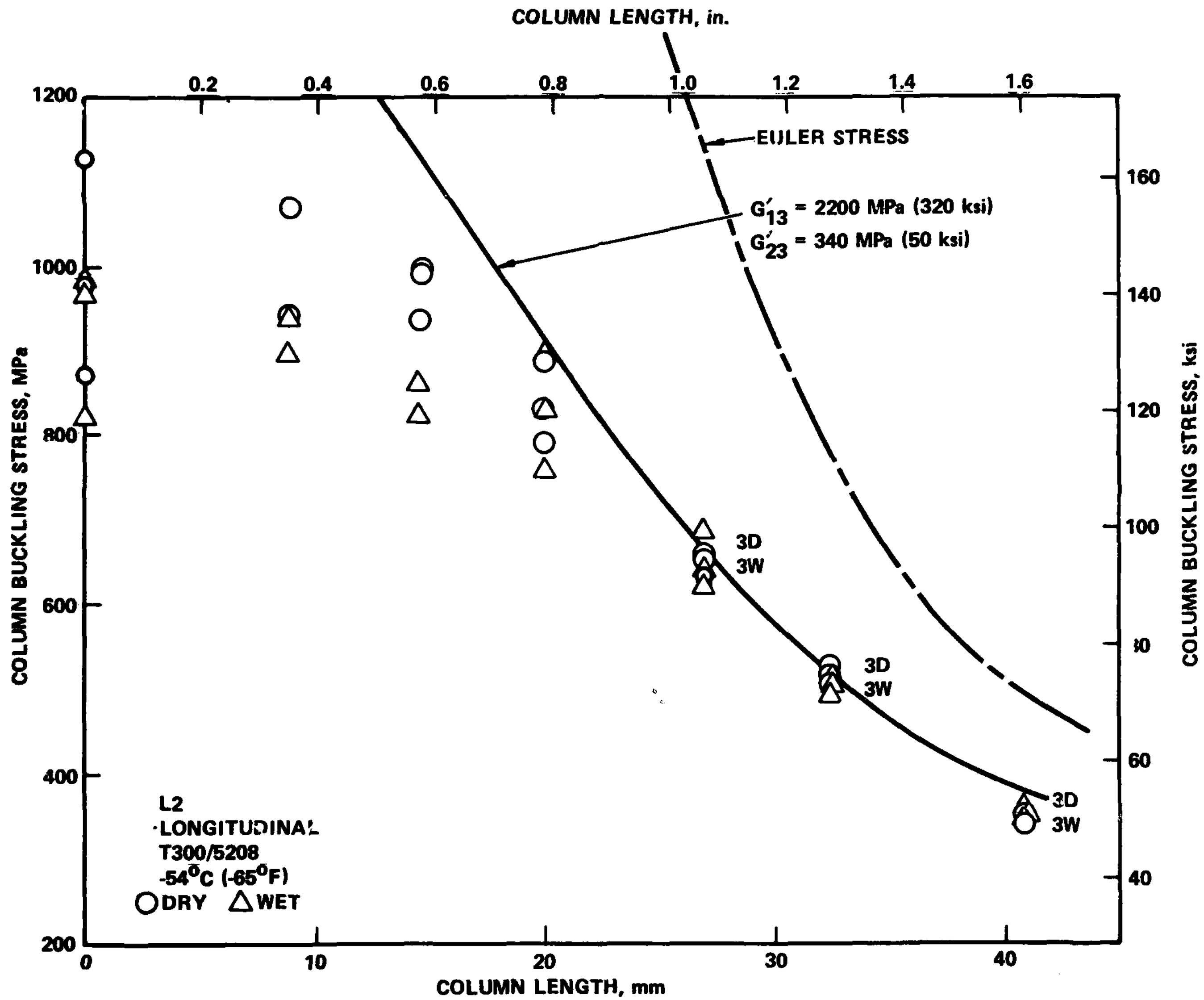

Figure 99. - Column test results at -54C for T300/5208 67% - 0° ply laminate L2L.

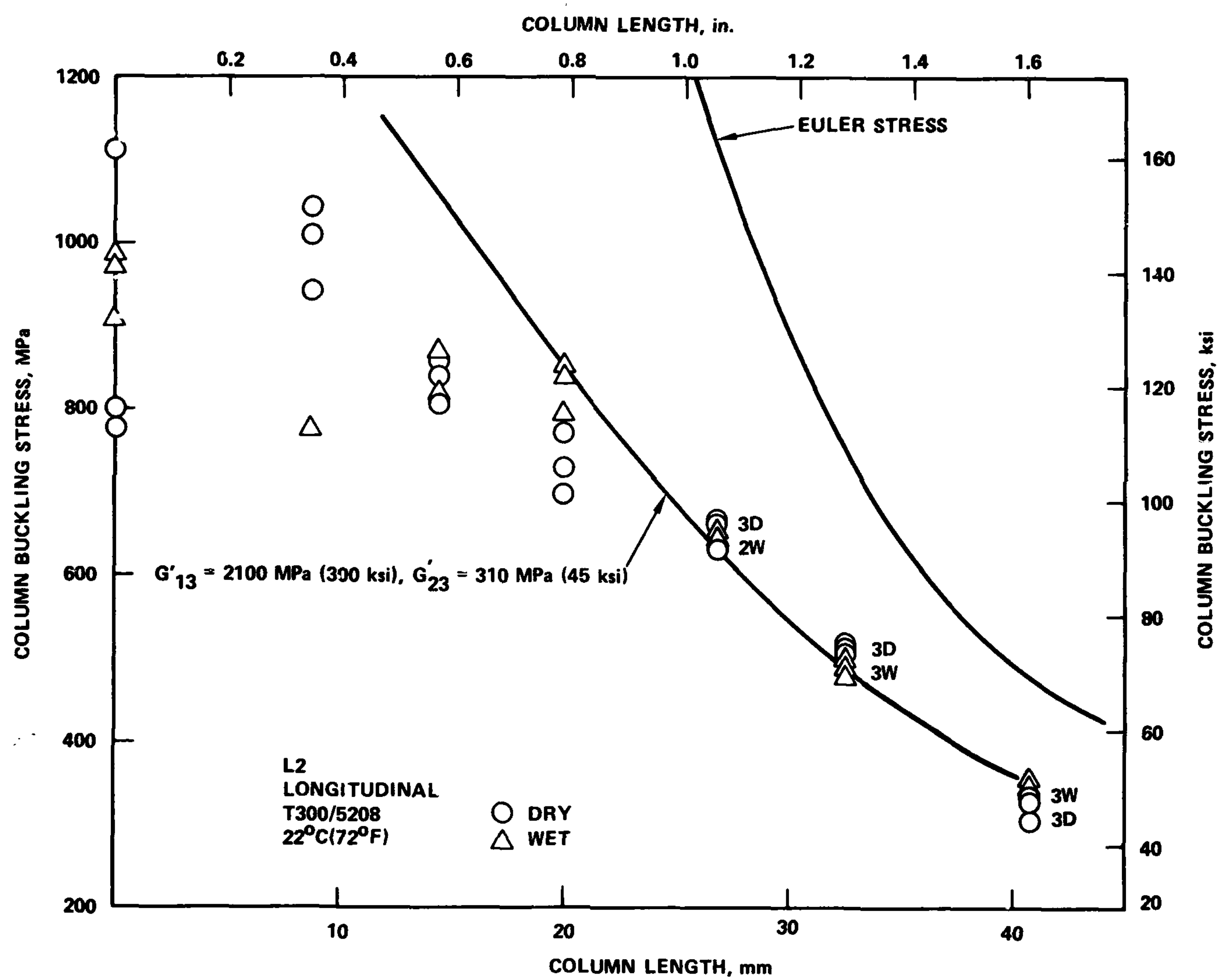

Figure 100. - Column test results at 22°C for T300/5208 67% - 0° ply laminate L2L.

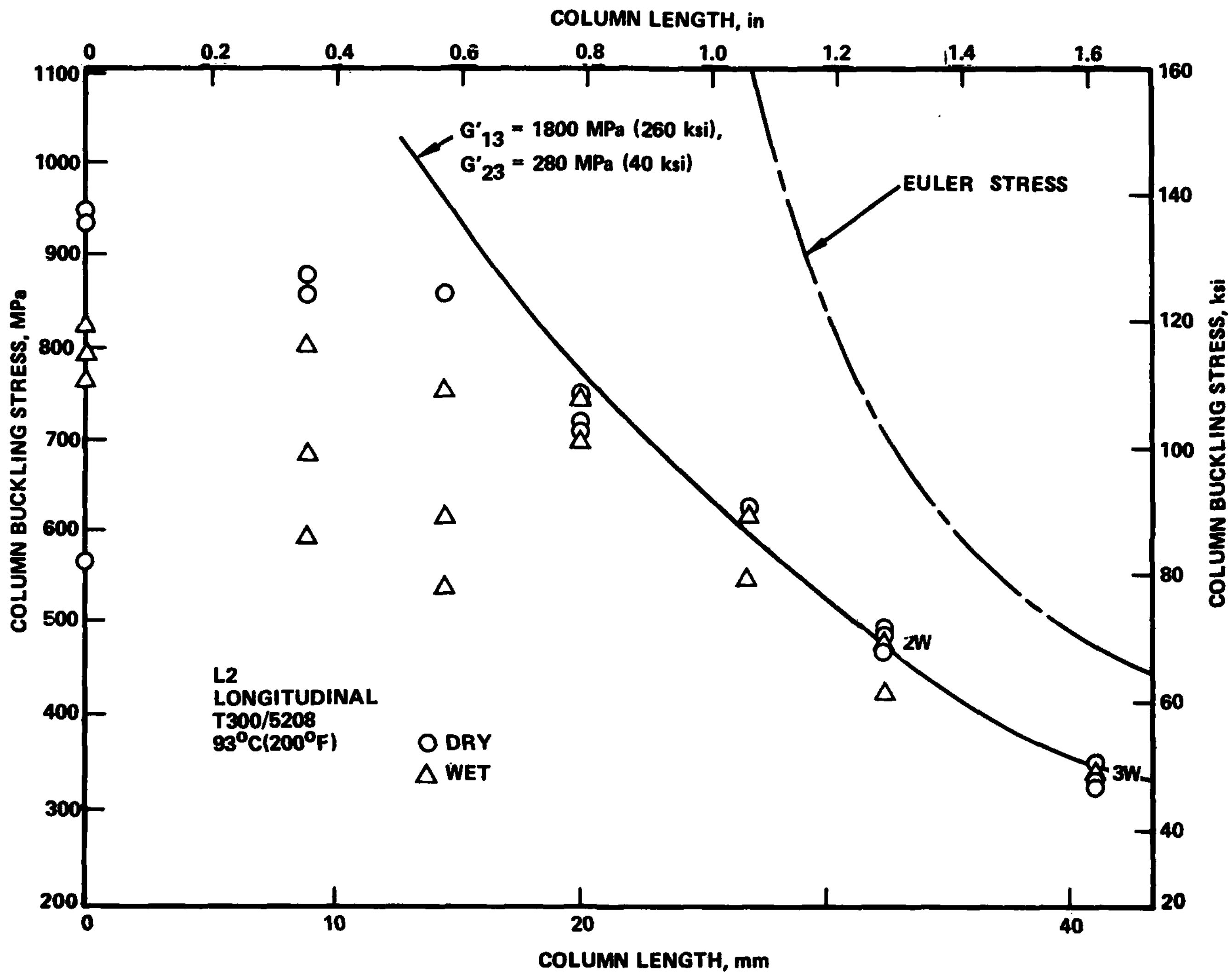

Figure 101. - Column test results at 93°C for T300/5208 67% - 0° ply laminate L2L.

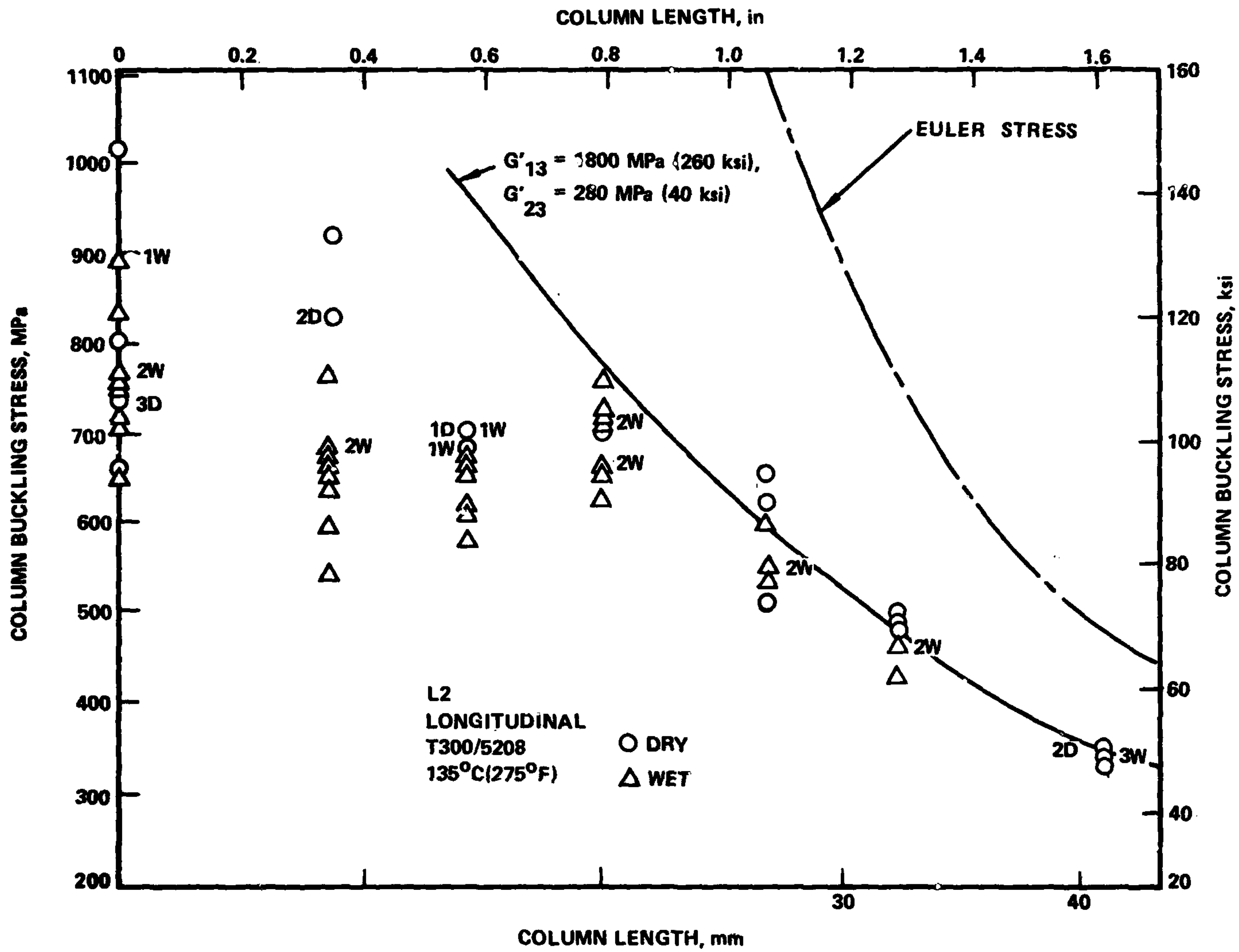

Figure 102. - Column test results at 135°C for T300/5208 67% - 0° ply laminate L2L.

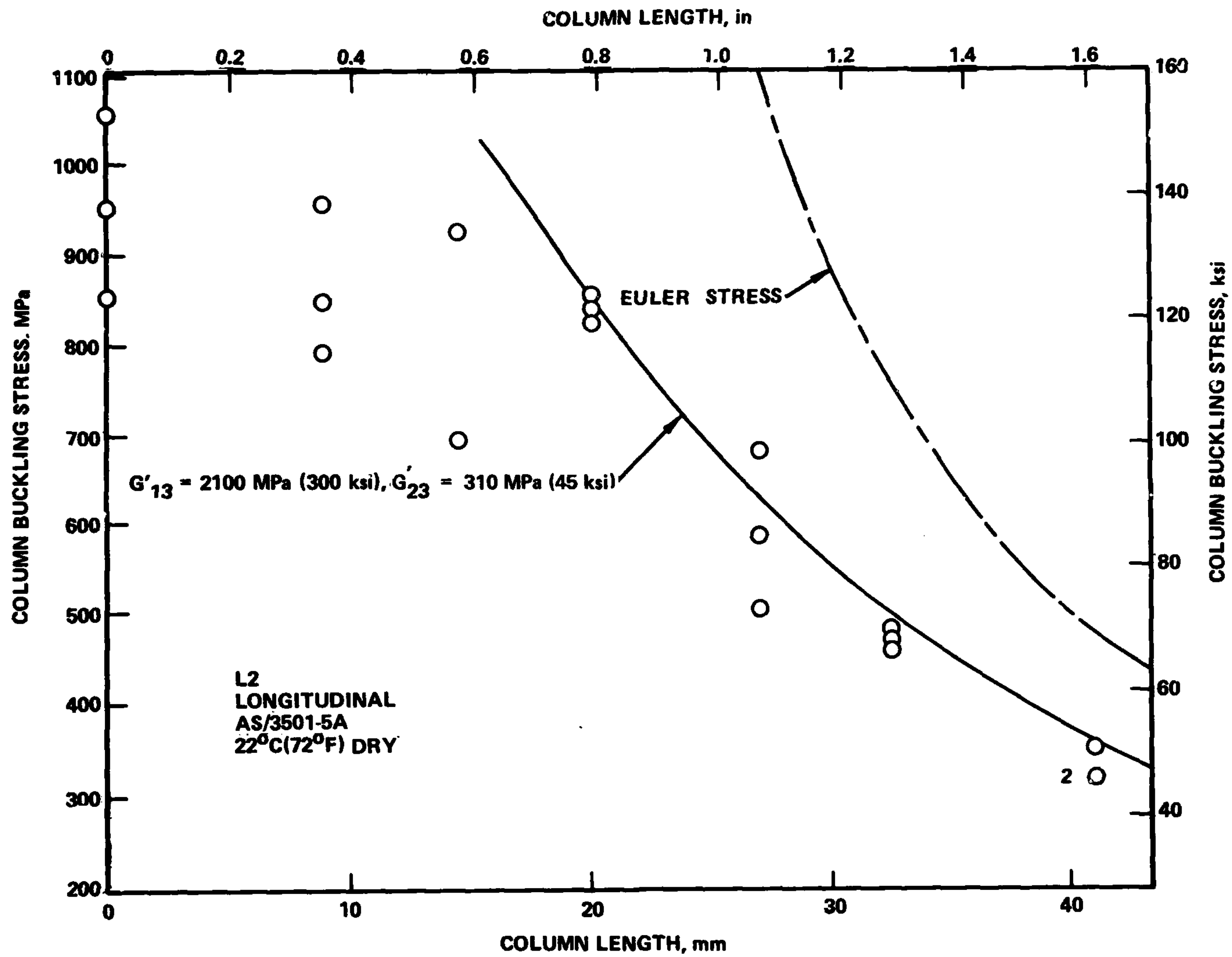

Figure 103. - Column test results at 22°C for AS/3501-5A 67% - 0° ply laminate L2L.

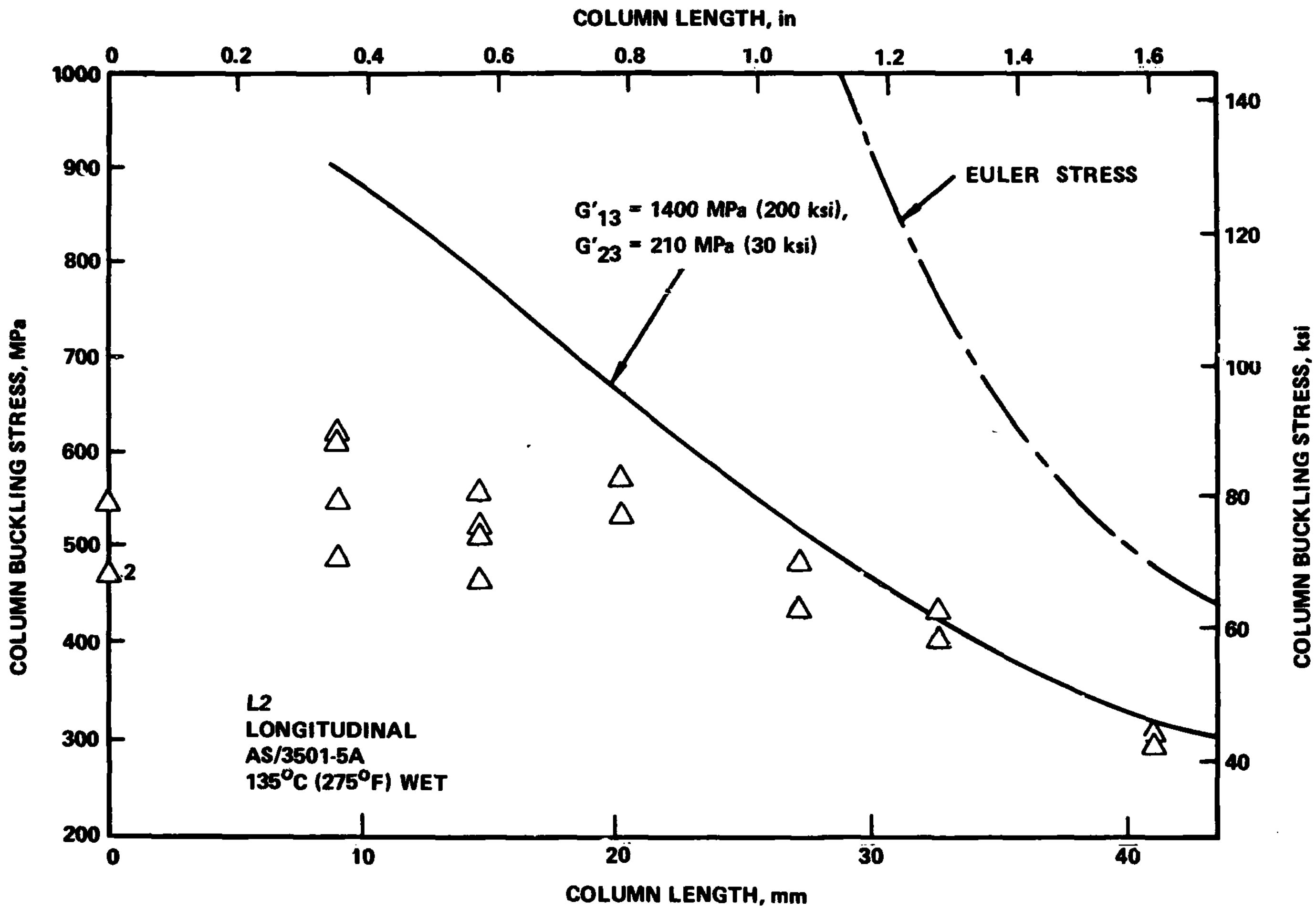

Figure 104. - Column test results at 135°C for AS/3501-5A 67% - 0° ply laminate L2L.

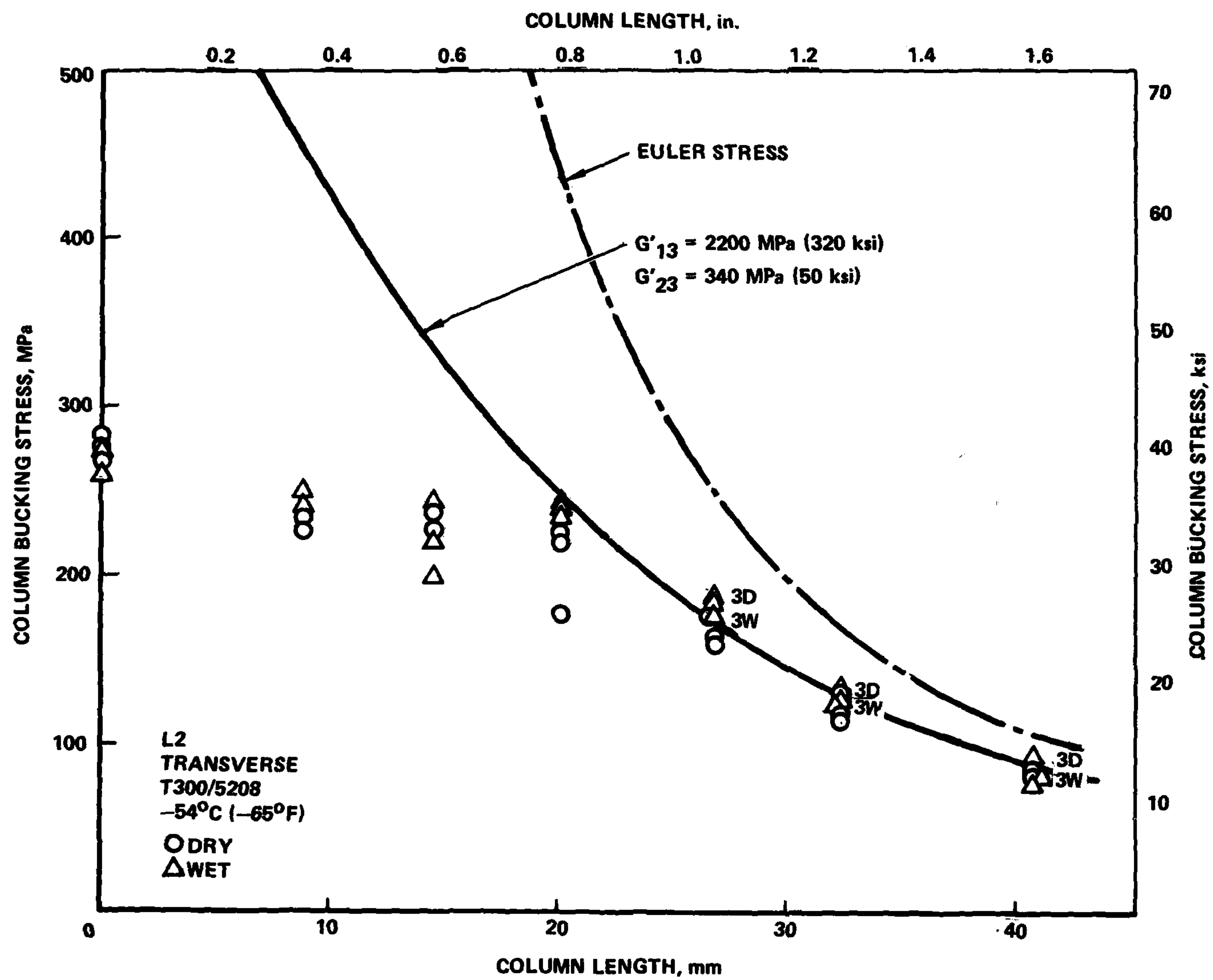

Figure 105. - Column test results at -54°C for T300/5208 67% - 90° ply laminate L2T.

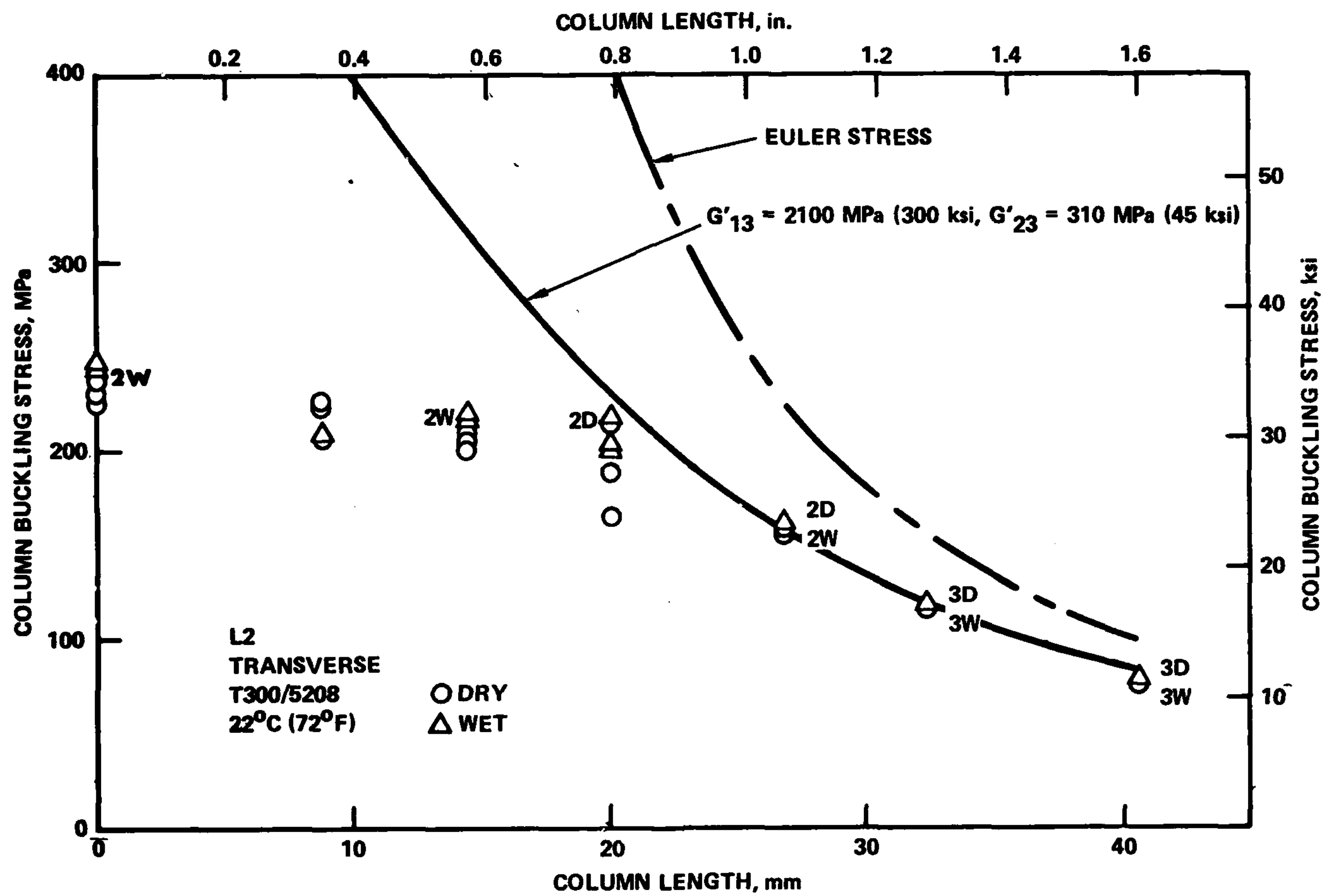

Figure 106. - Column test results at 22°C for T300/5208 67% - 90° ply laminate L2T.

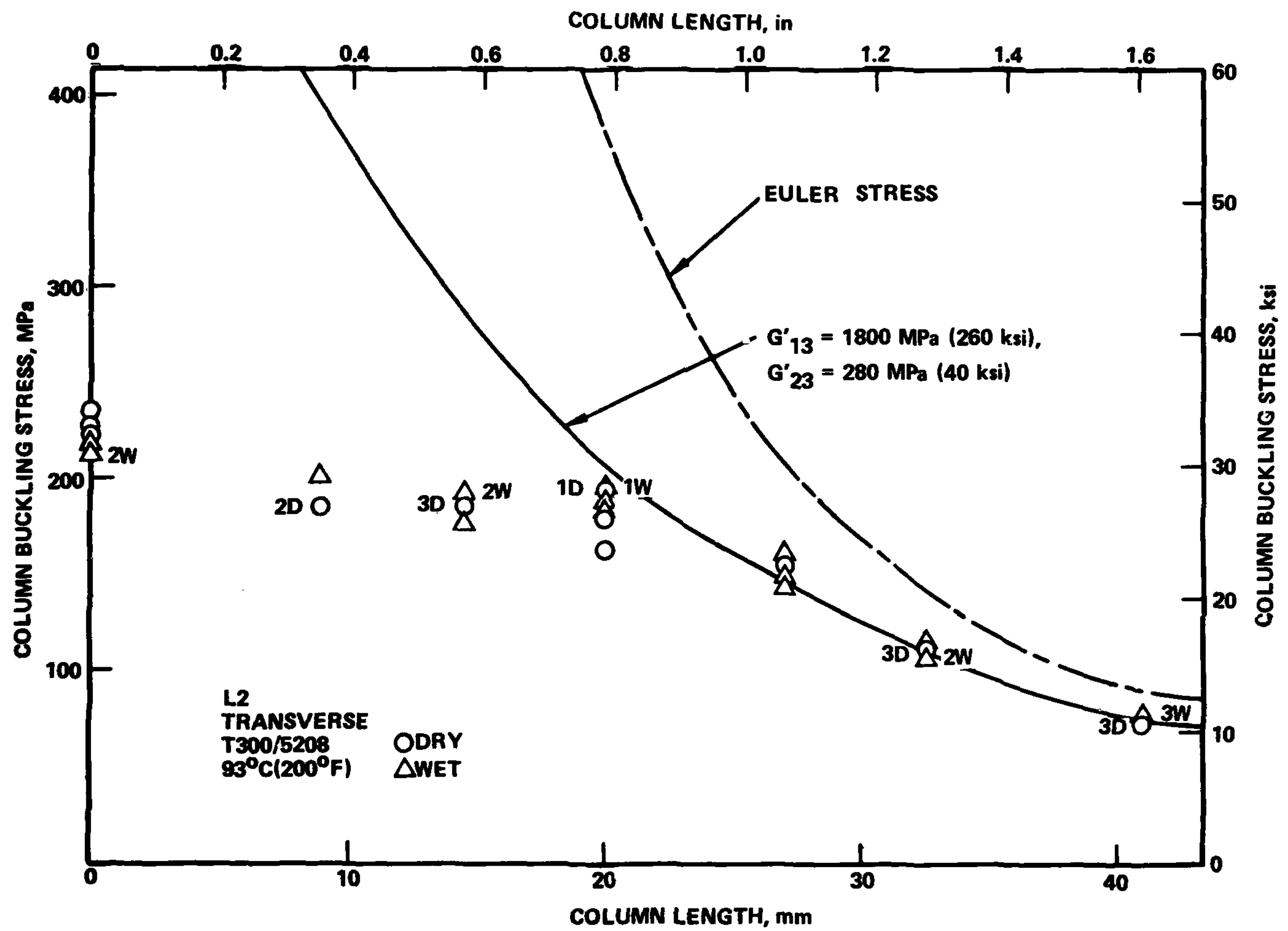

Figure 107. - Column test results at 93°C for T300/5208 67% - 90° ply laminate L2T.

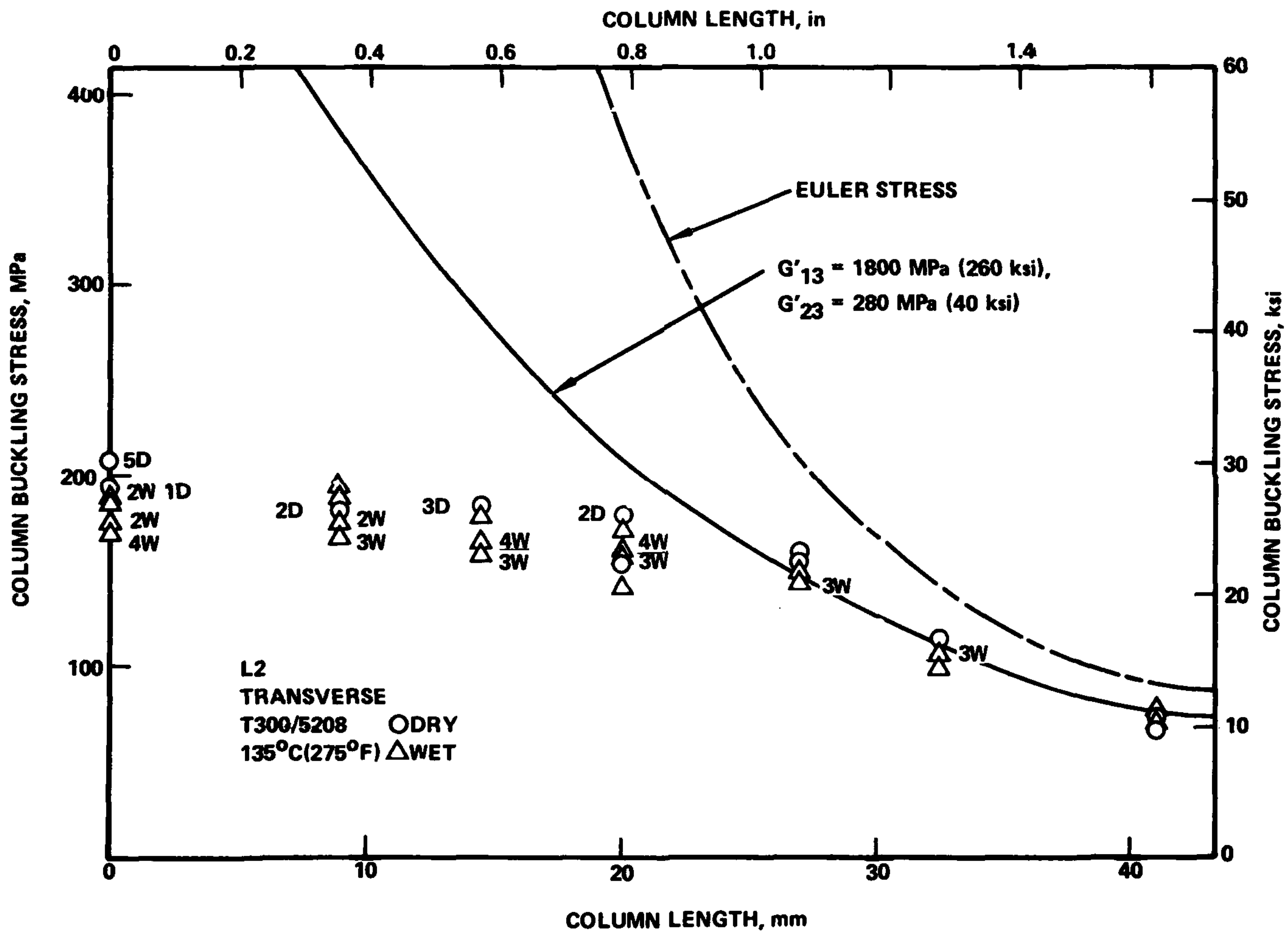

Figure 108. - Column test results at 135°C for T300/5208 67% - 90° ply laminate L2T.

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THE EFFECT OF ENVIRONMENT ON THE COMPRESSIVE STRENGTHS OF LAMIN--ETC(U)

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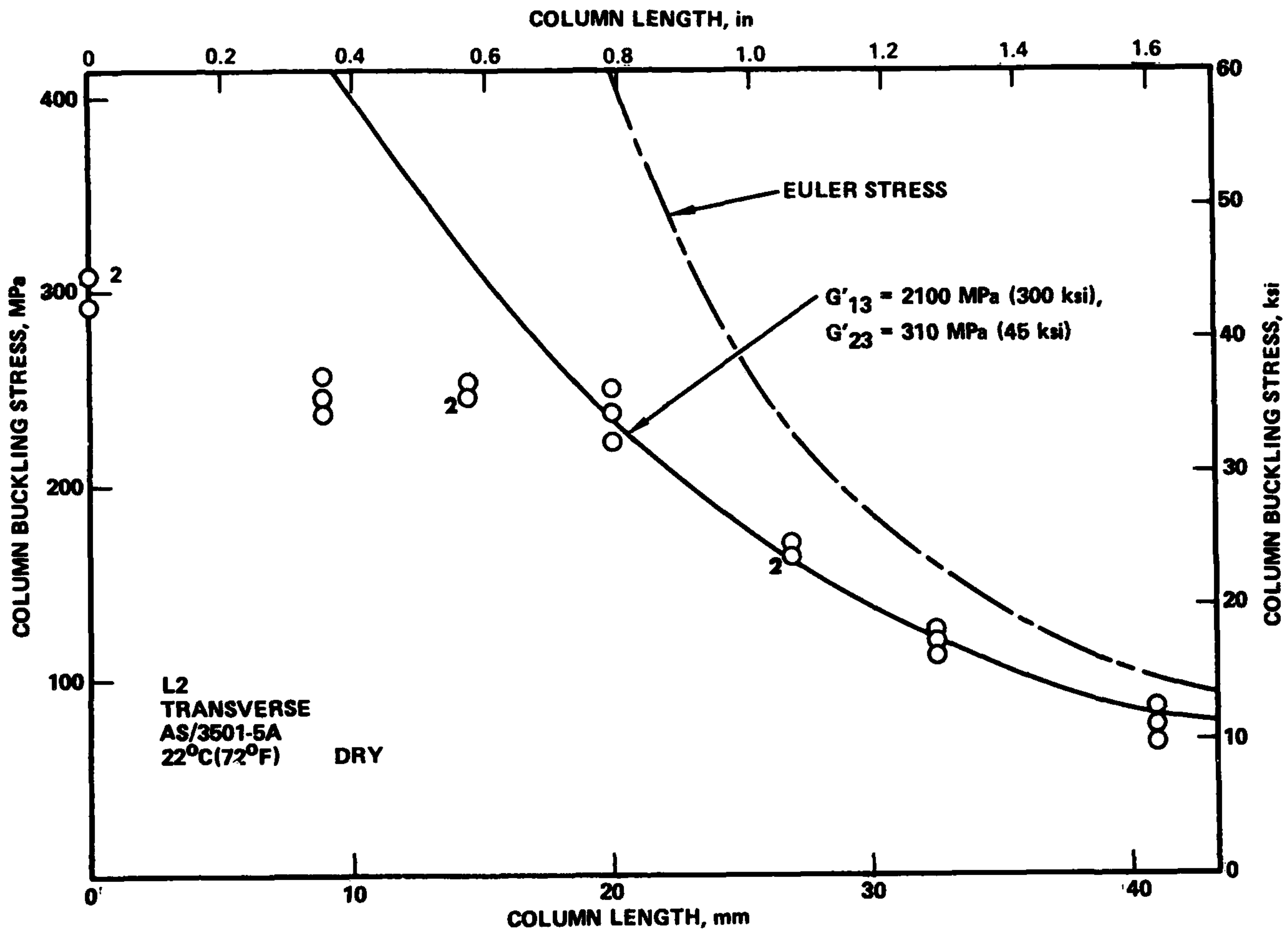


Figure 109. - Column test results at 22°C for AS/3501-5A 67% - 90° ply laminate L2T.

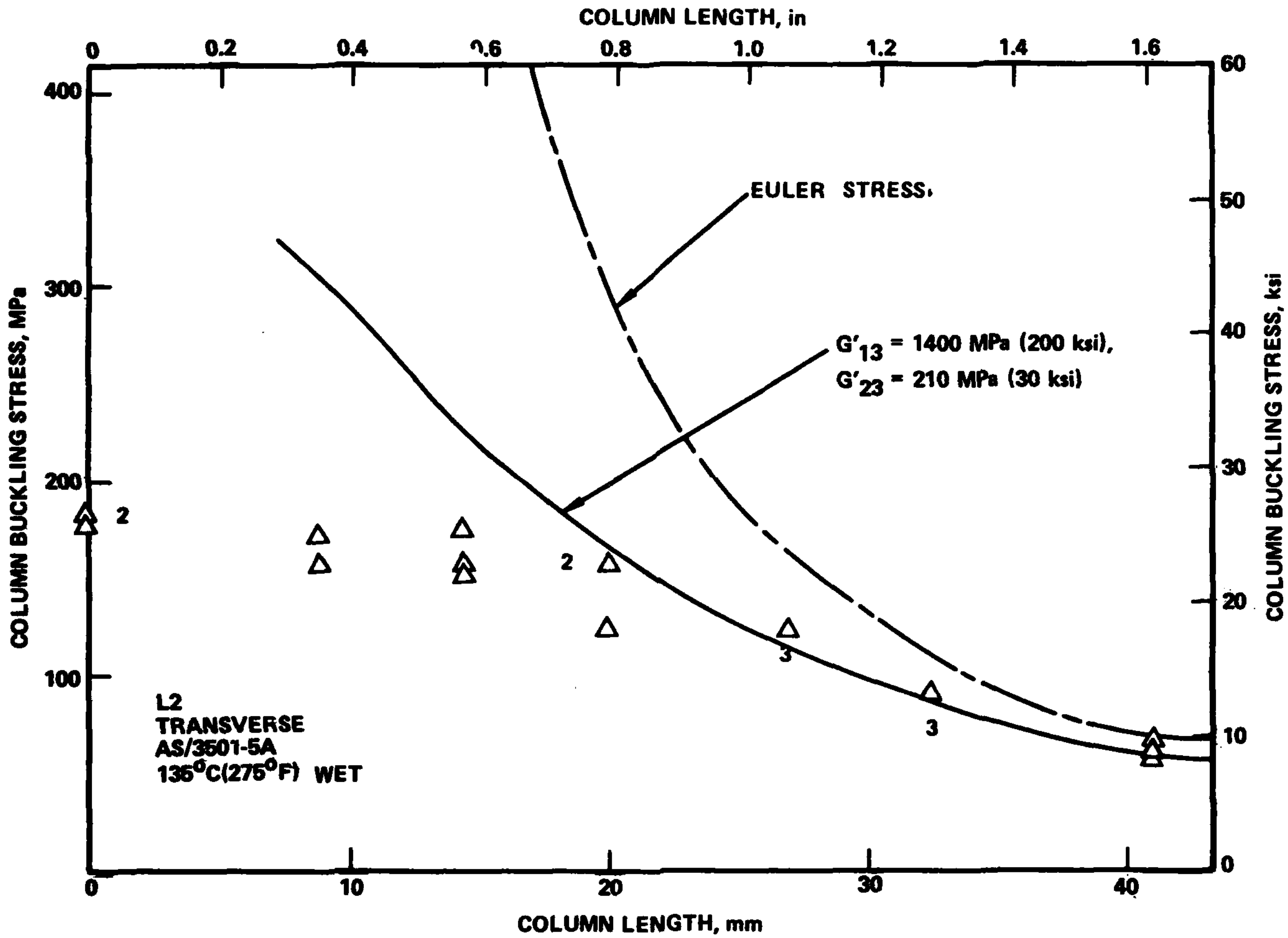


Figure 110. - Column test results at 135°C for AS/3501-5A 67% 90° ply laminate L2T.

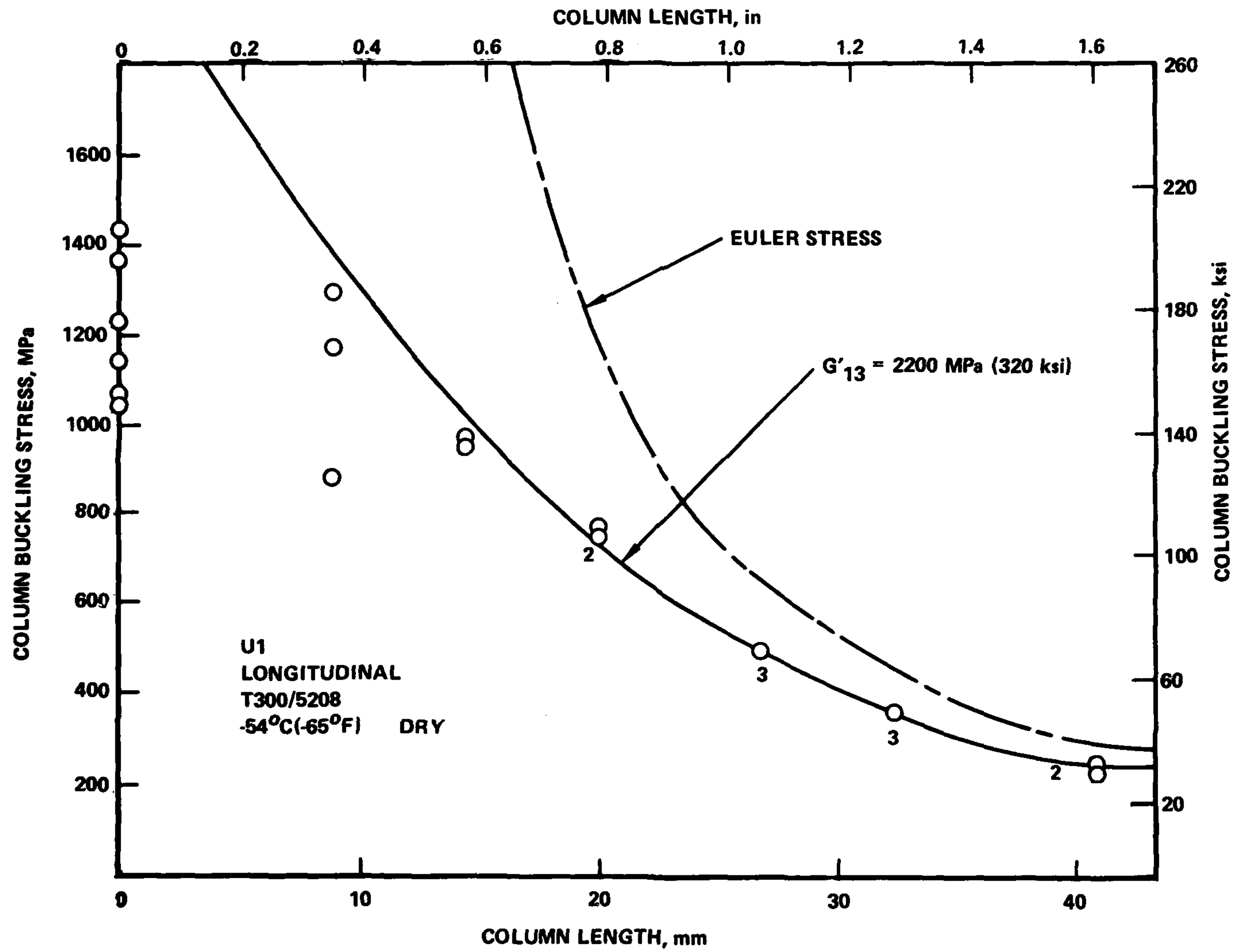


Figure 111. - Column test results at -54C for T300/5208 0° - unidirectional laminate U1L.

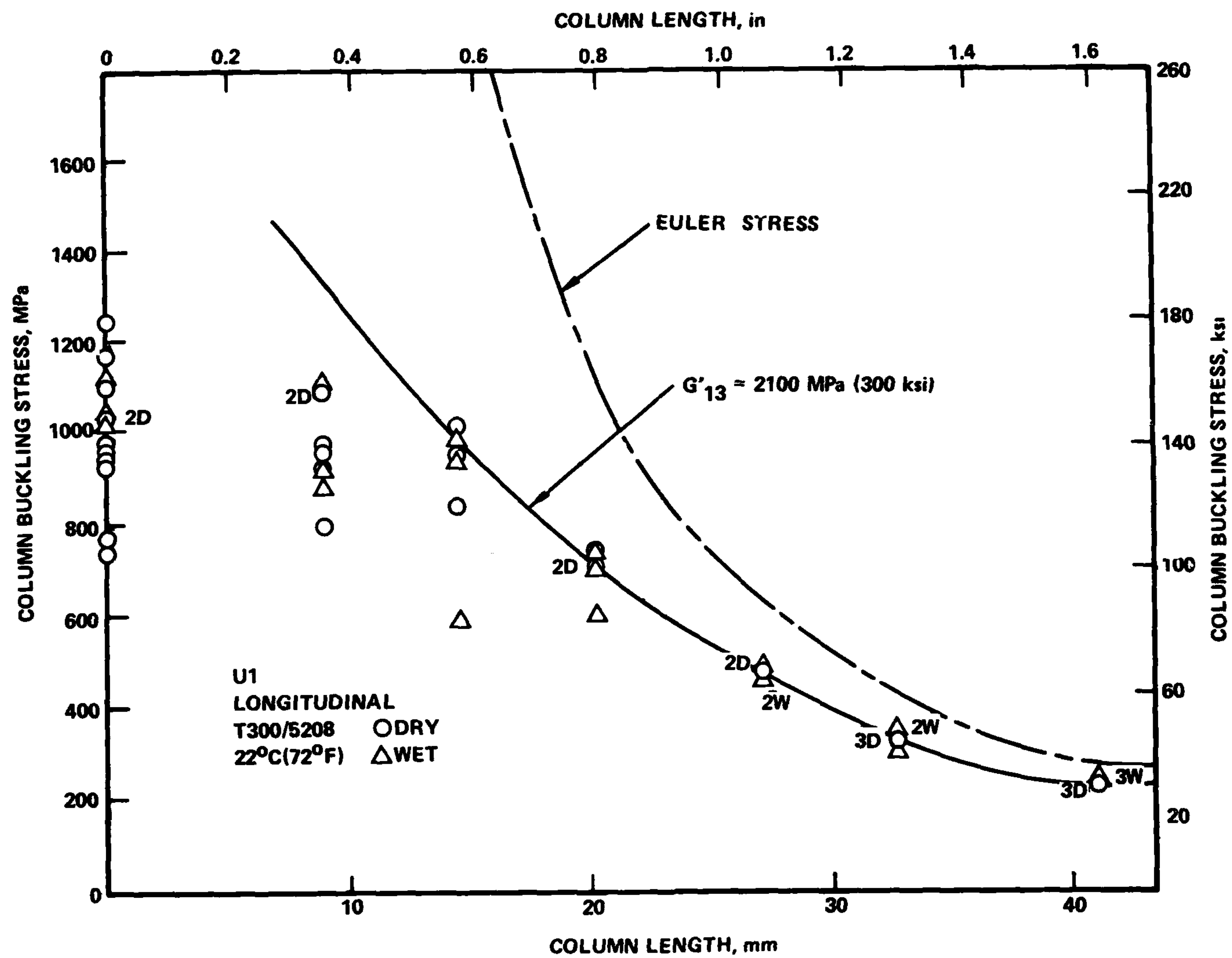


Figure 112. - Column test results at 22°C for T300/5208 0° - unidirectional laminate U1L.

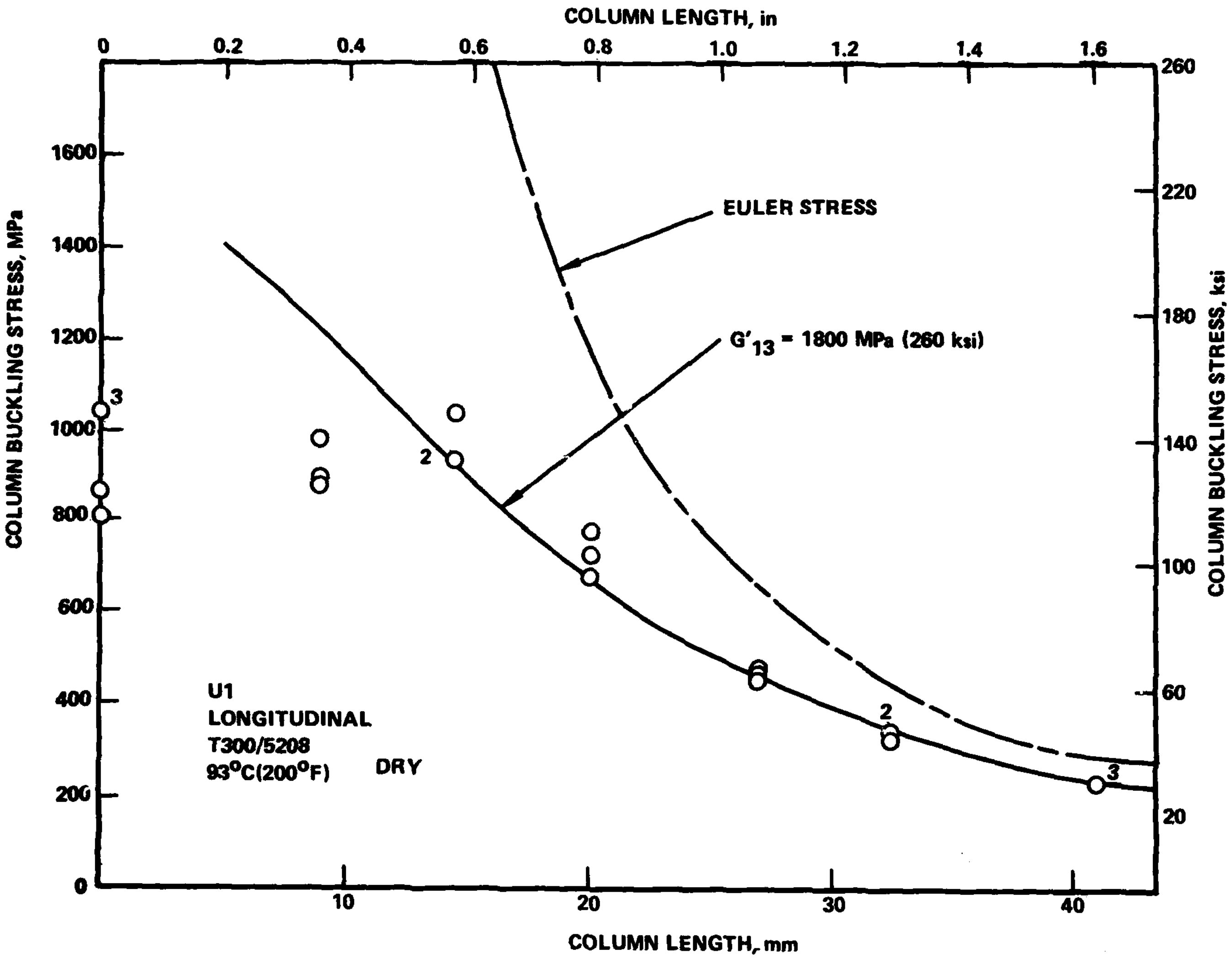


Figure 113. - Column test results at 93°C for T300/5208 0° - unidirectional laminate U1L.

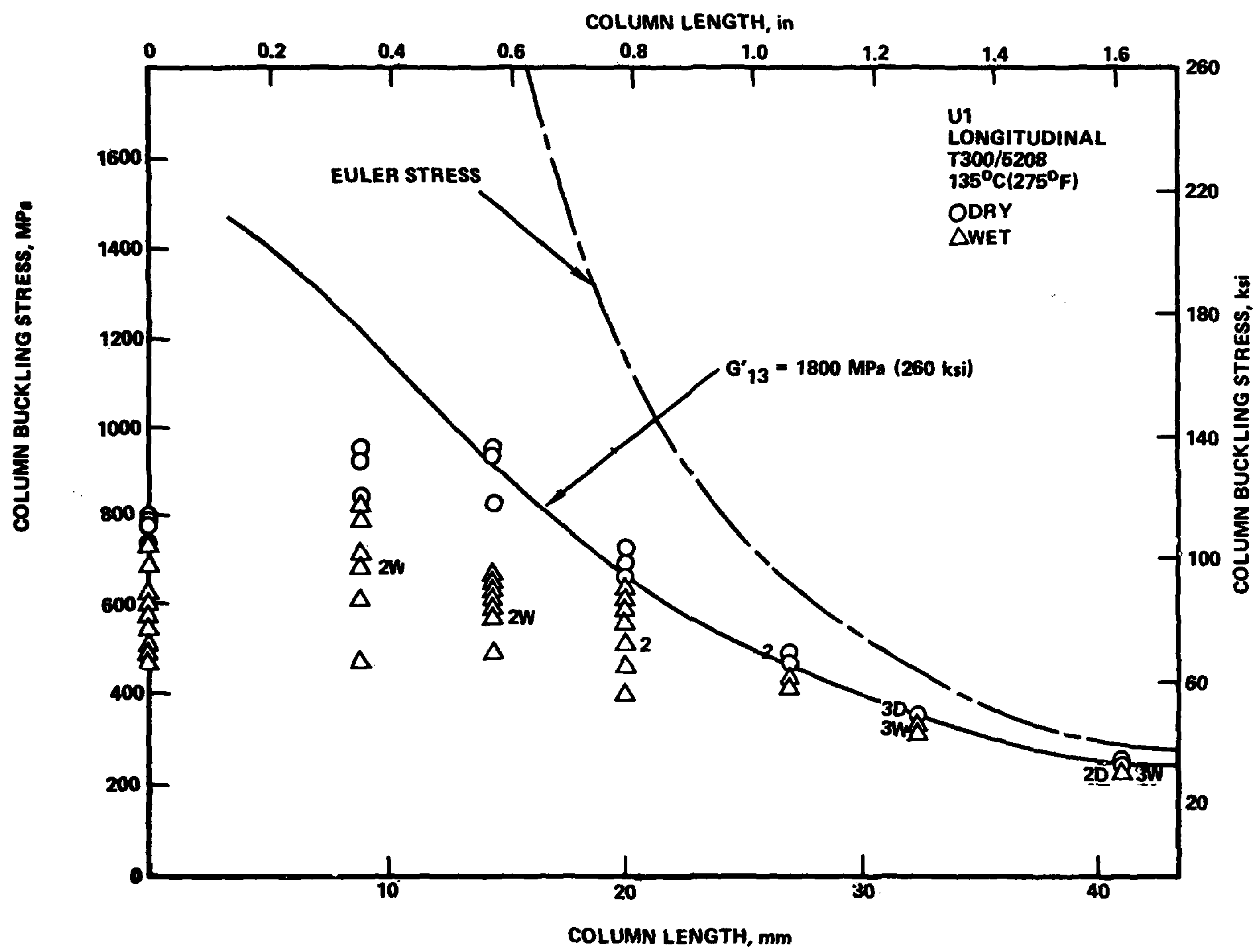


Figure 114. - Column test results at 135°C for T300/5208 0° - unidirectional laminate U1L.

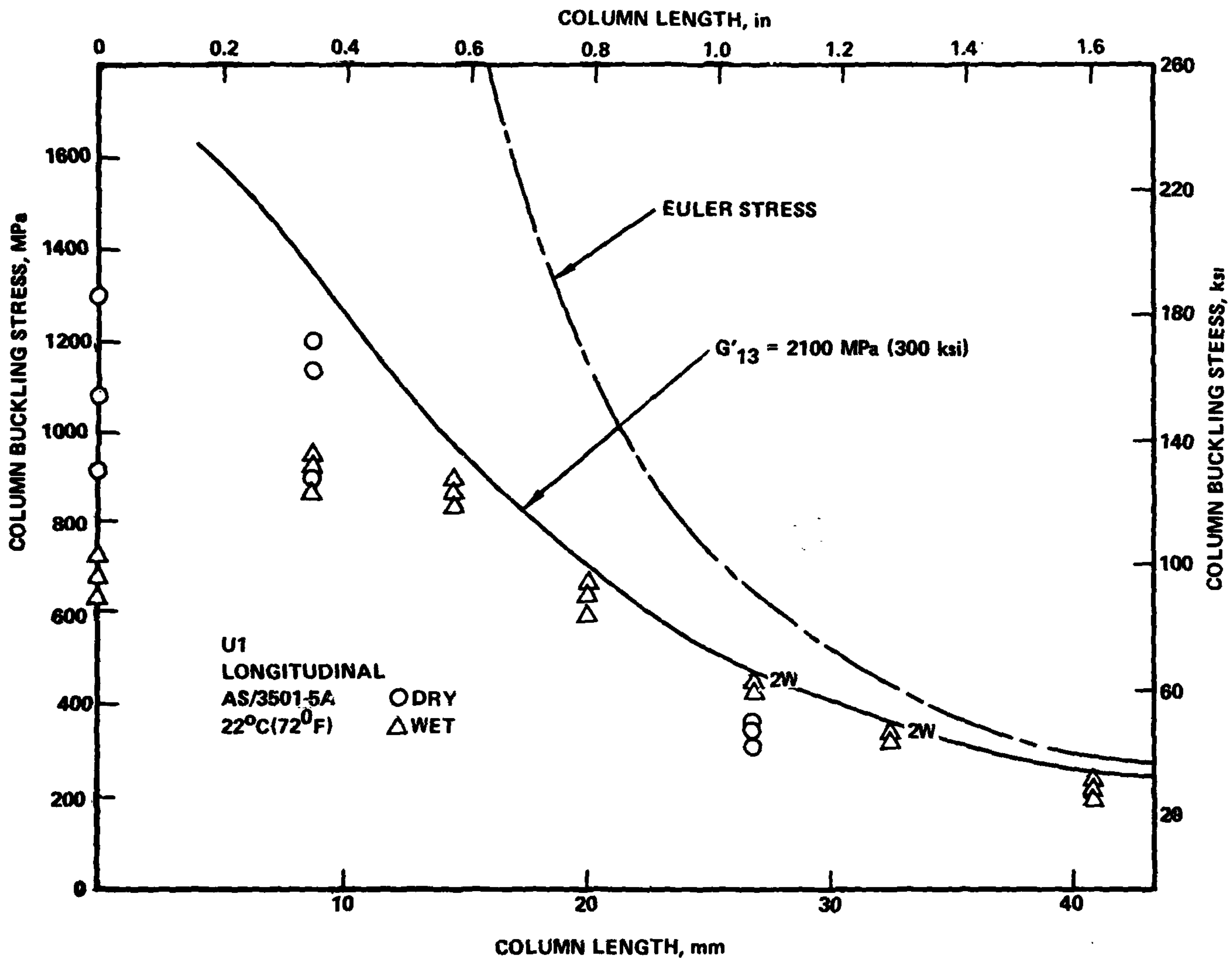


Figure 115. - Column test reults at 22°C for AS/3501-5A 0° - unidirectional laminate U1L

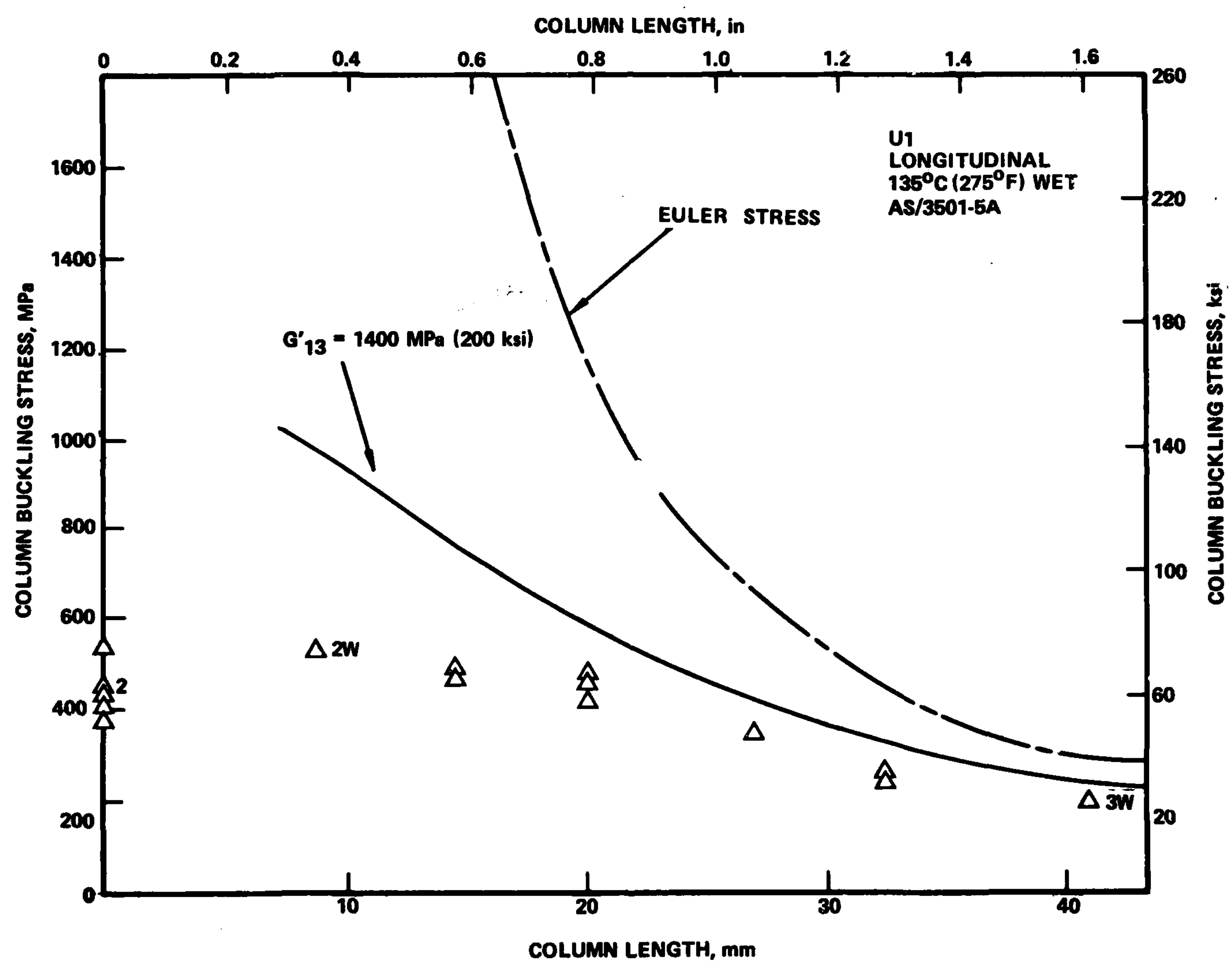


Figure 116. - Column test results at 135°C for AS/3501-5A 0° - unidirectional laminate U1L

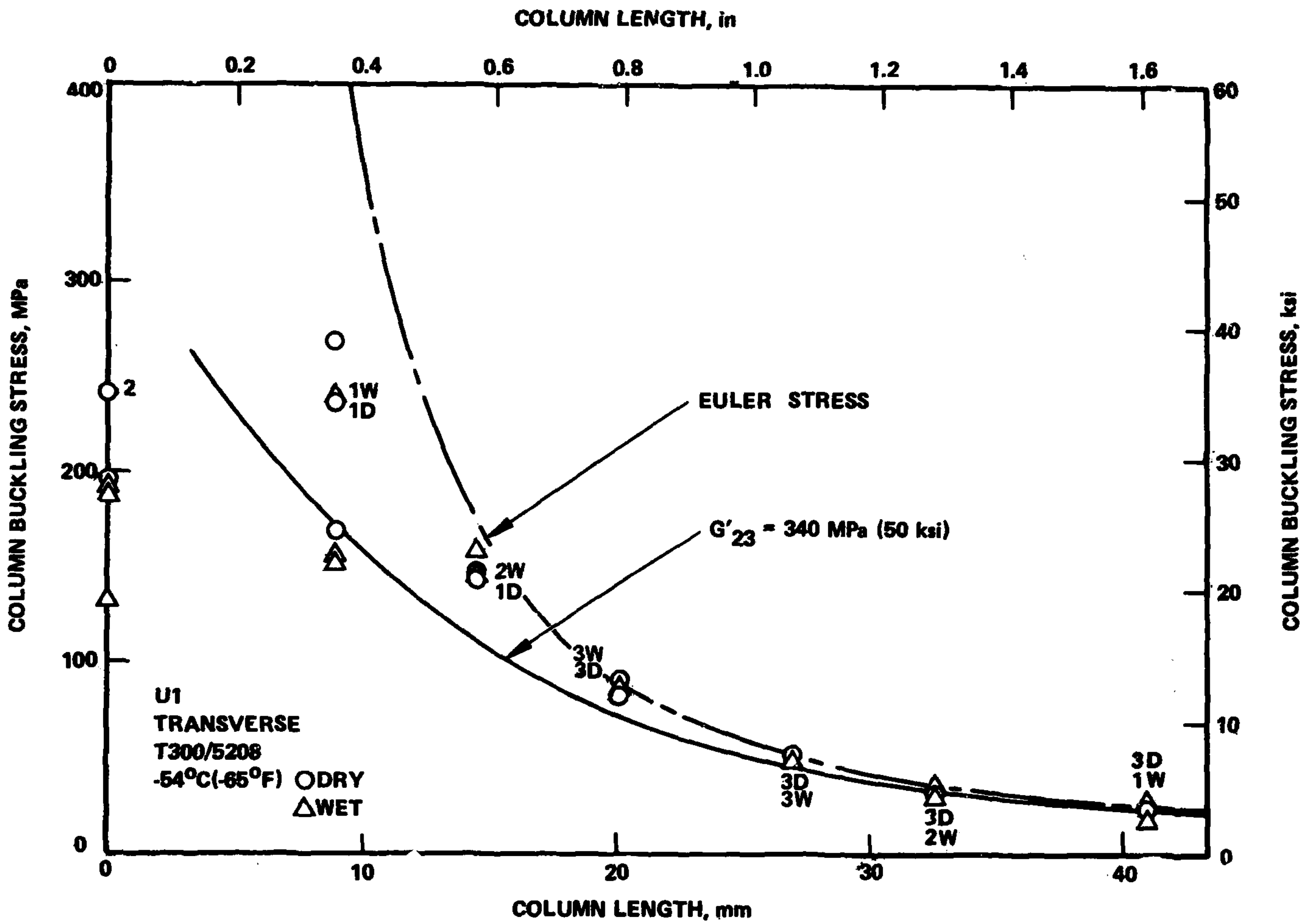


Figure 117. - Column test results at -54°C for T300/5208 90° - unidirectional laminate U1T.

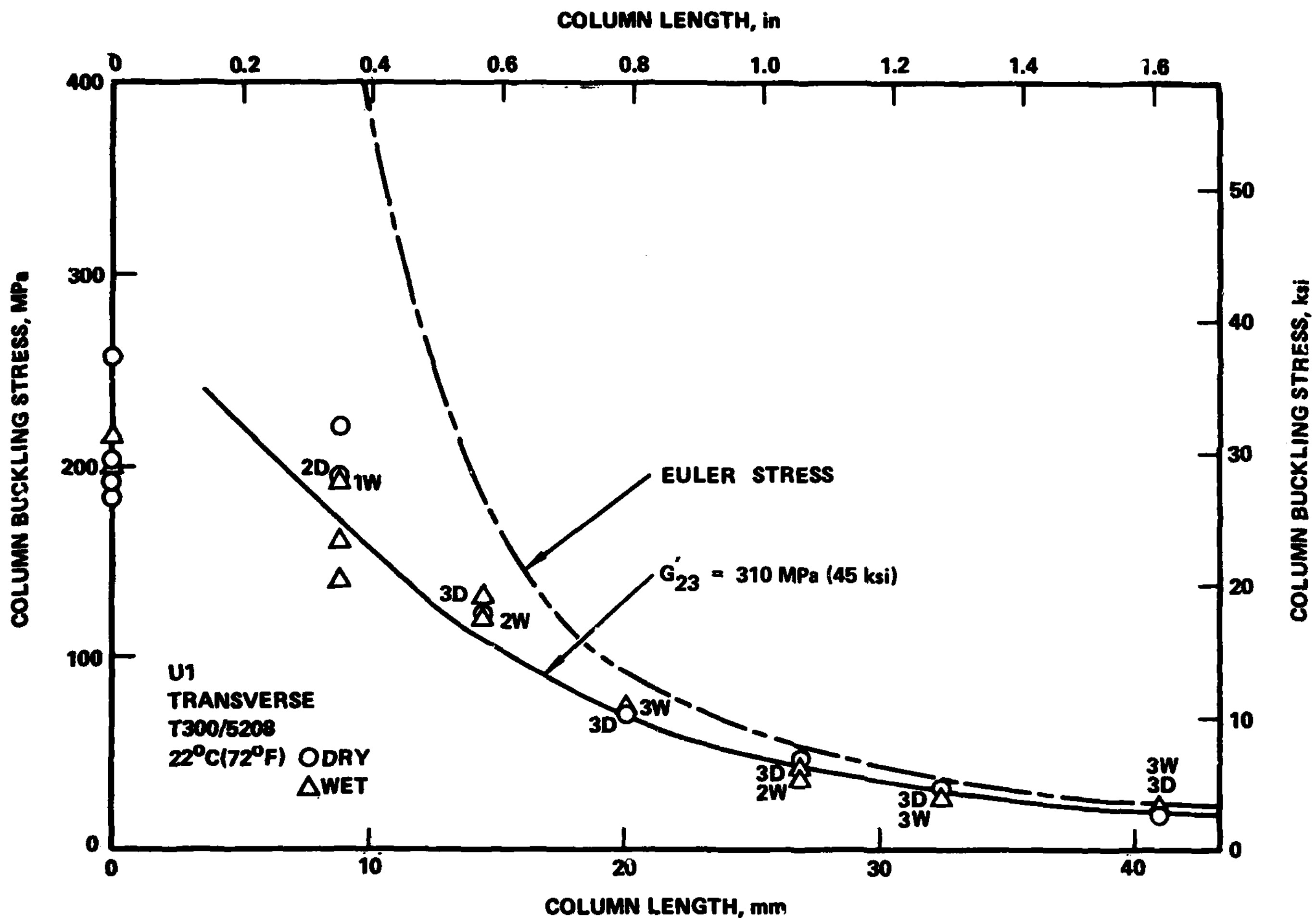


Figure 118. - Column test results at 22°C for T300/5208 90° -- unidirectional laminate U1T.

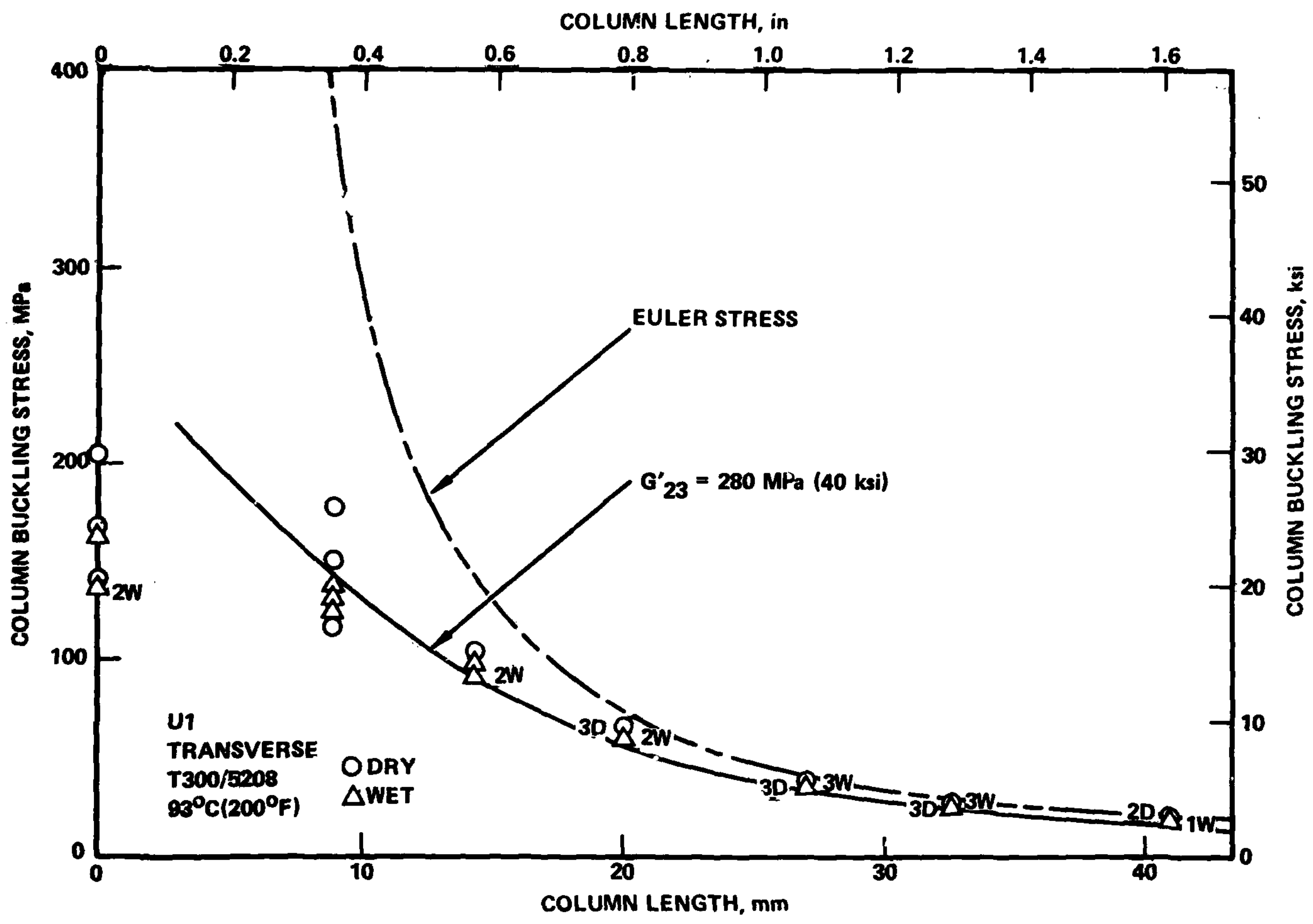


Figure 119. - Column test results at 93°C for T300/5208 90° - unidirectional laminate U1T.

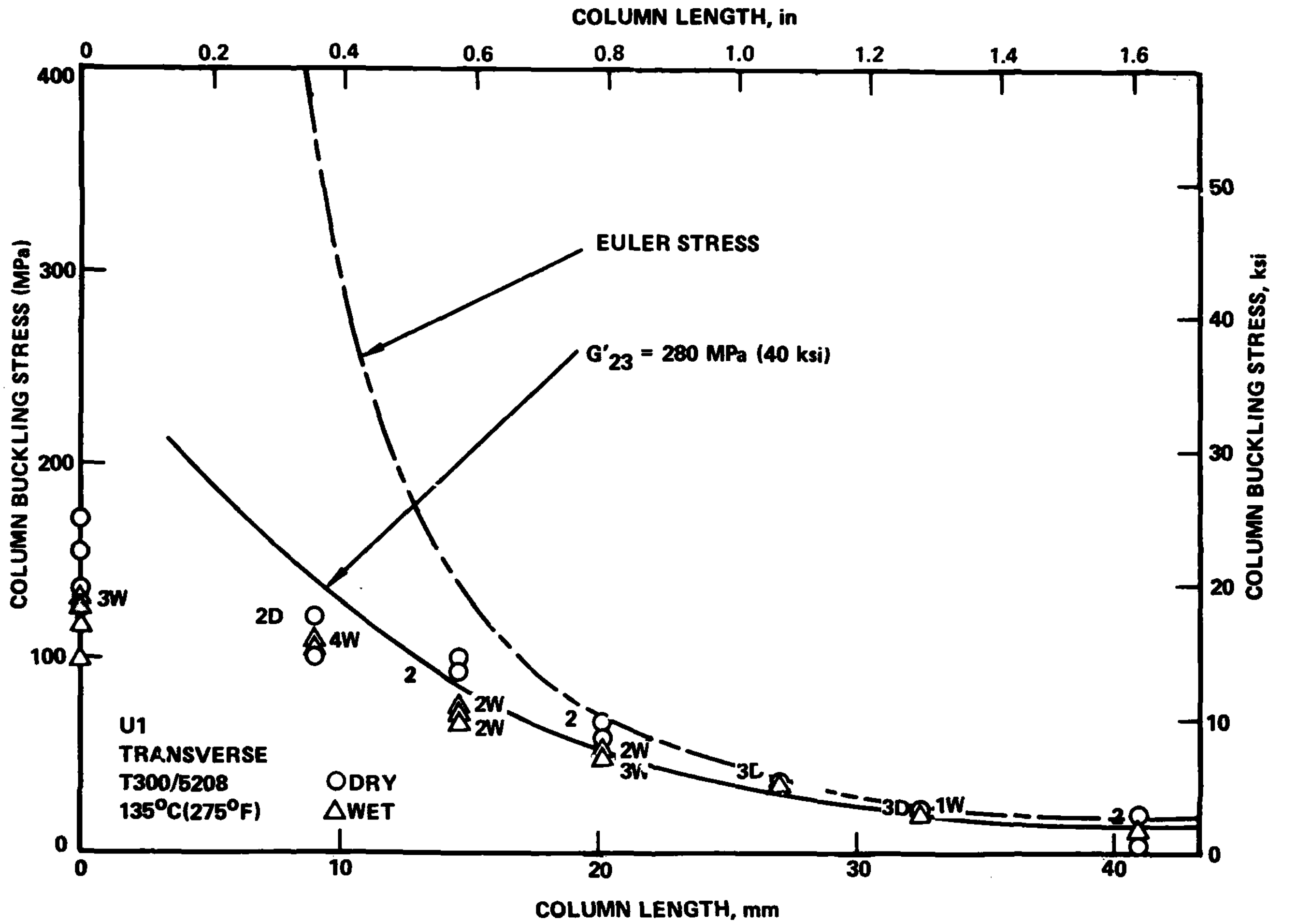


Figure 120. - Column test results at 135°C for T300/5208 90° - undirectional laminate U1T.

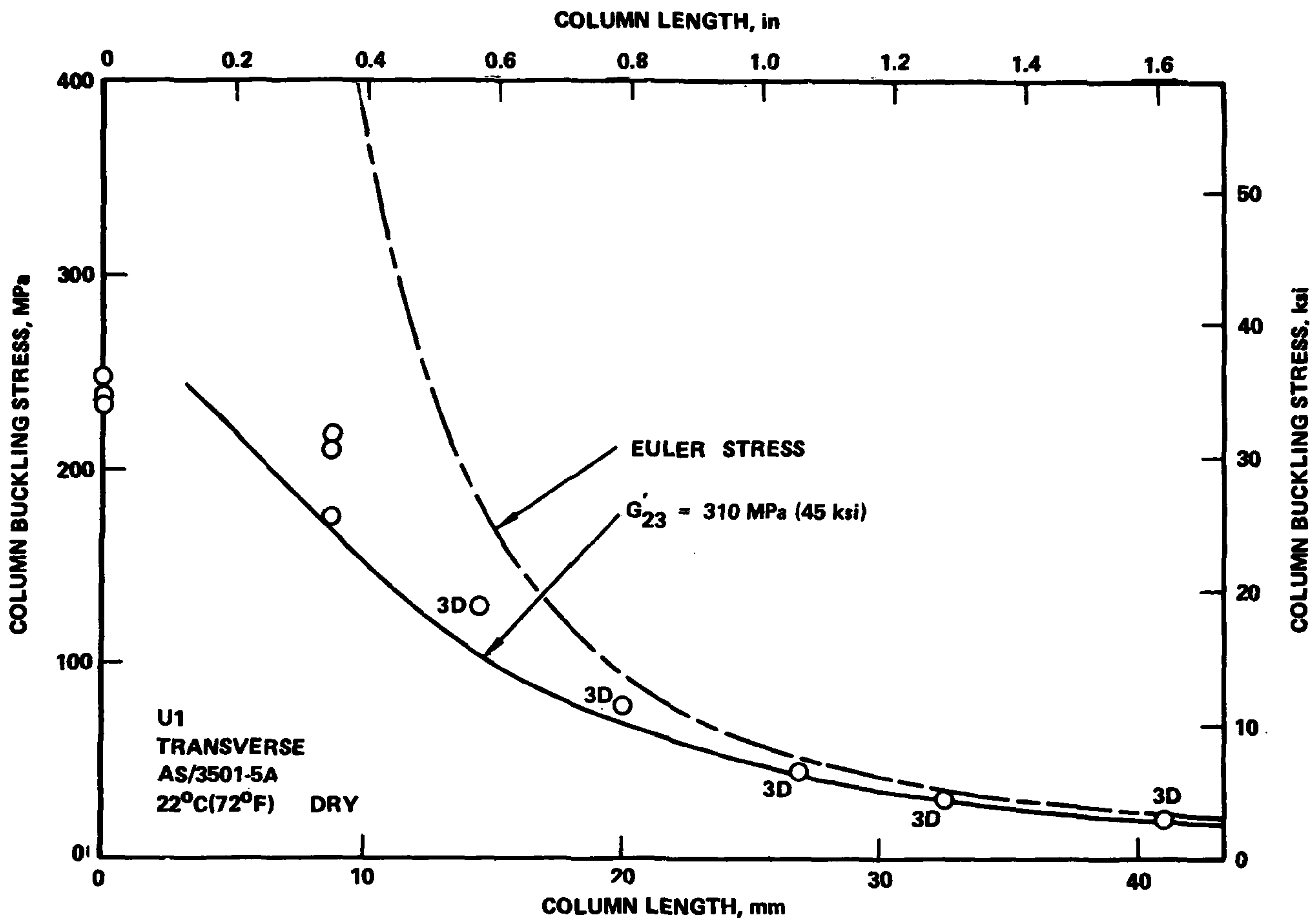


Figure 121. - Column test results at 22°C for AS/3501-5A 90° - unidirectional laminate U1T.

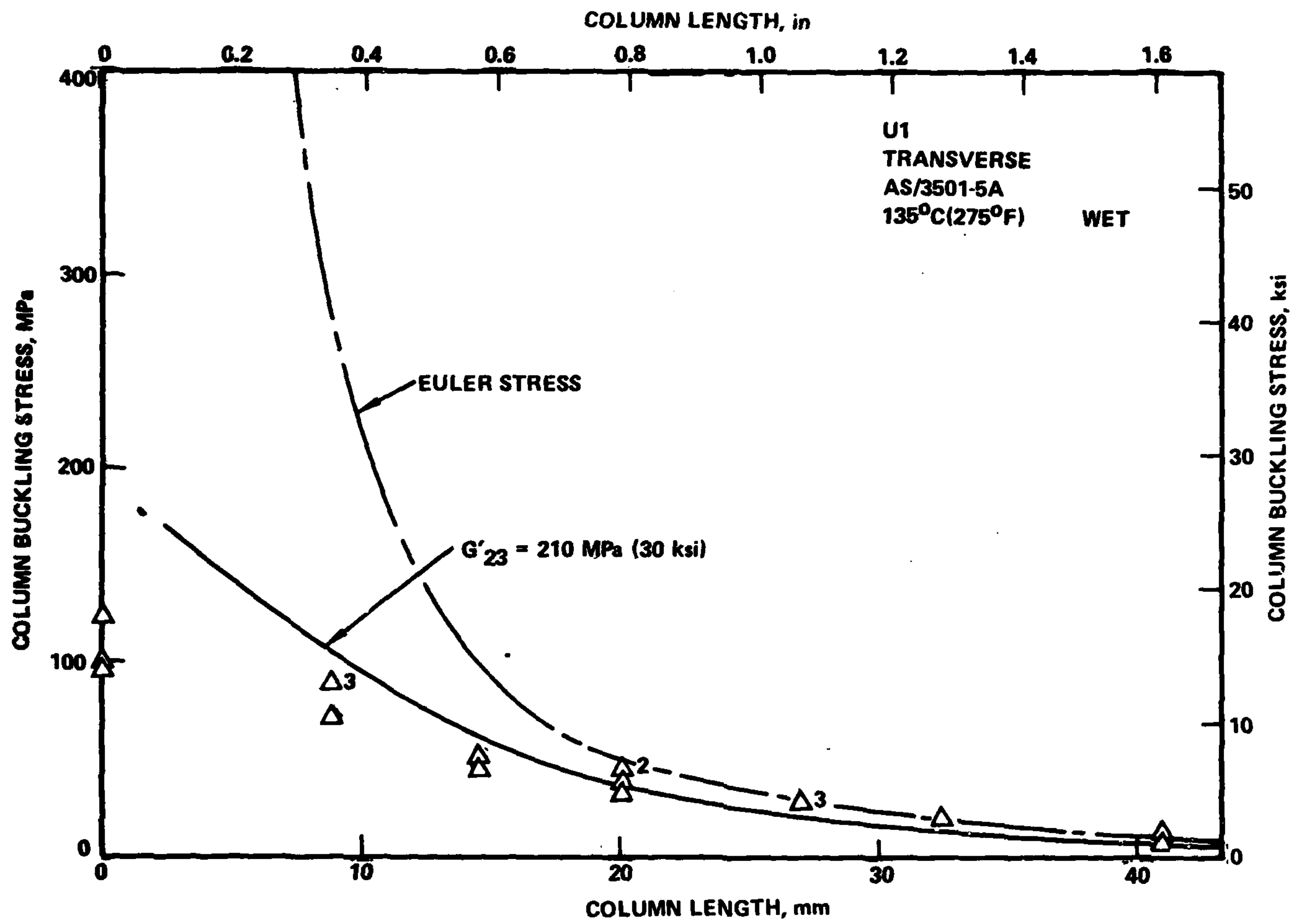


Figure 122. - Column test results at 135°C for AS/3501-5A 90° - unidirectional laminate U1T.

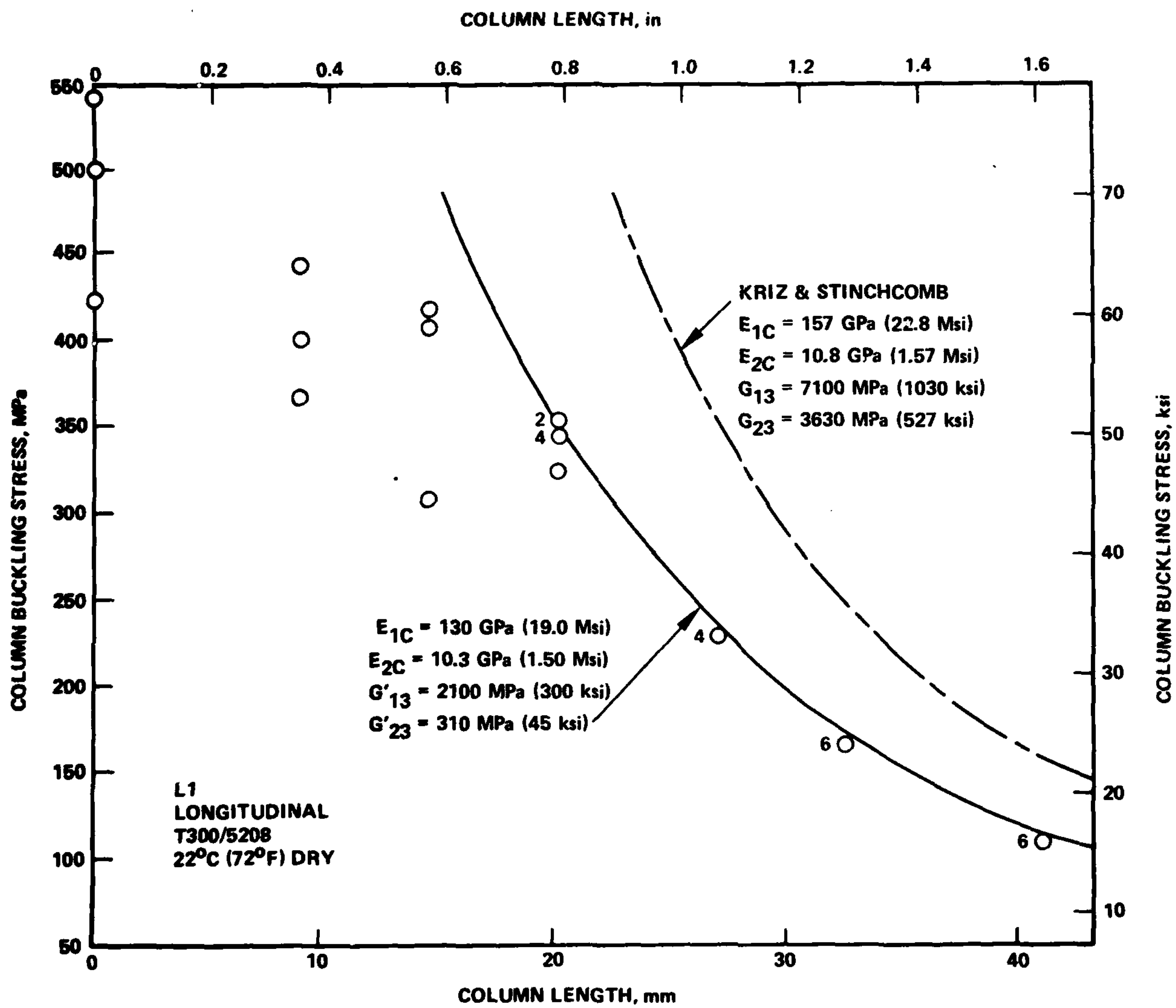


Figure 123. - Column analysis results for laminate L1L with values of G'_{13} and G'_{23} determined experimentally by Kriz and Stinchcomb.

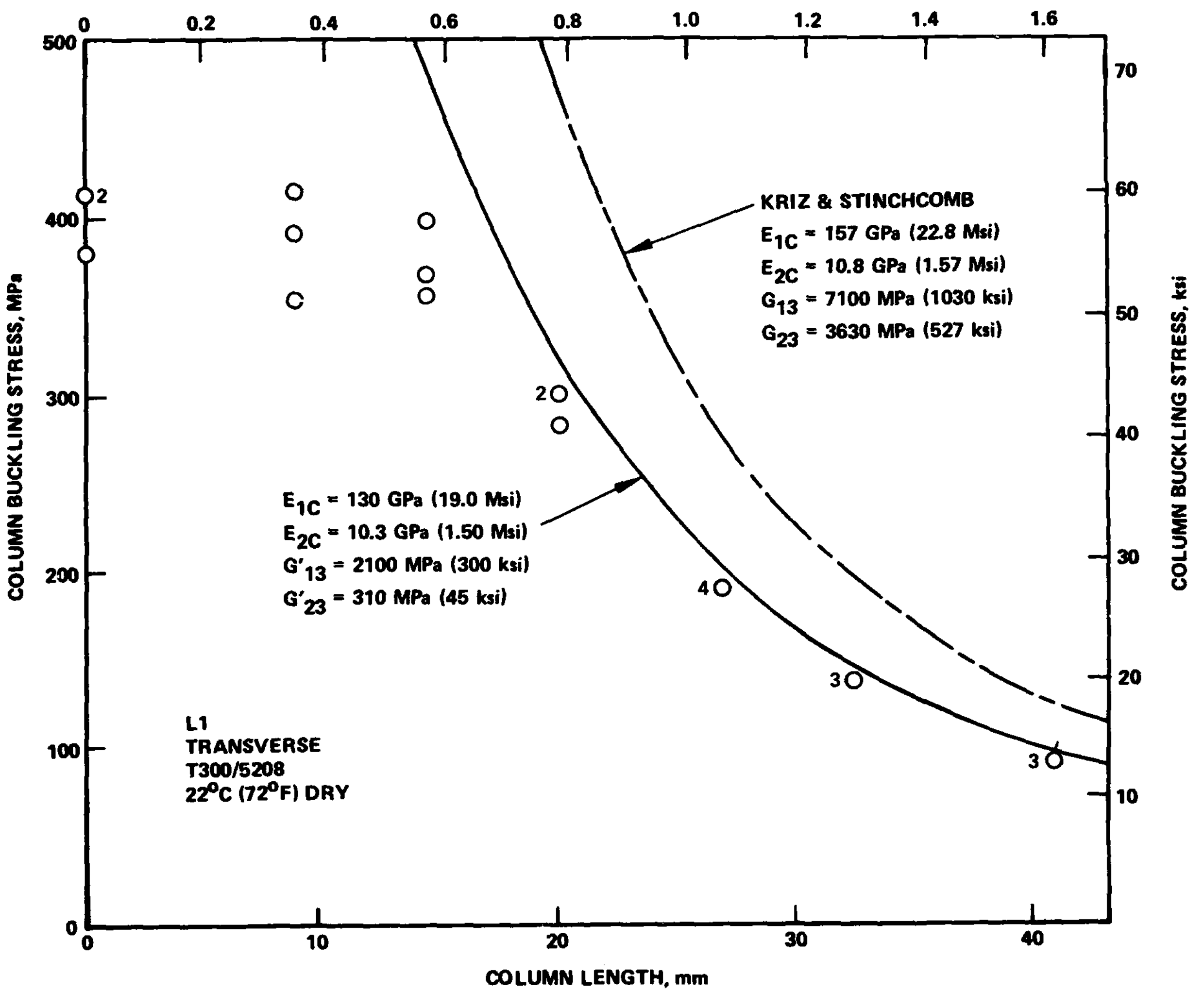


Figure 124. - Column analysis results for laminate L1T with values of G'_{13} and G'_{23} determined experimentally by Kriz and Stinchcomb.

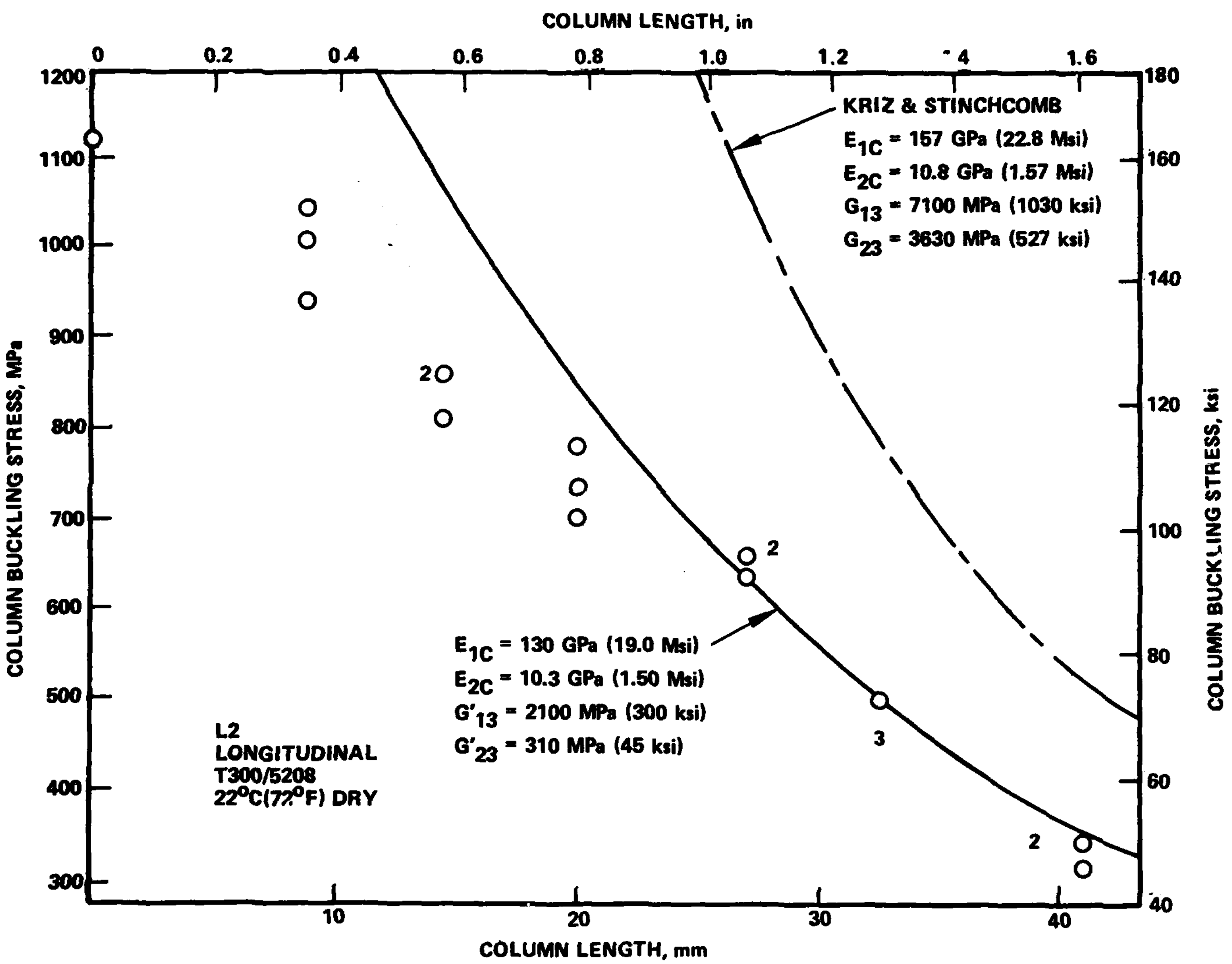


Figure 125. - Column analysis results for laminate L1L with values of G'_{13} and G'_{23} determined experimentally by Kriz and Stinchcomb.

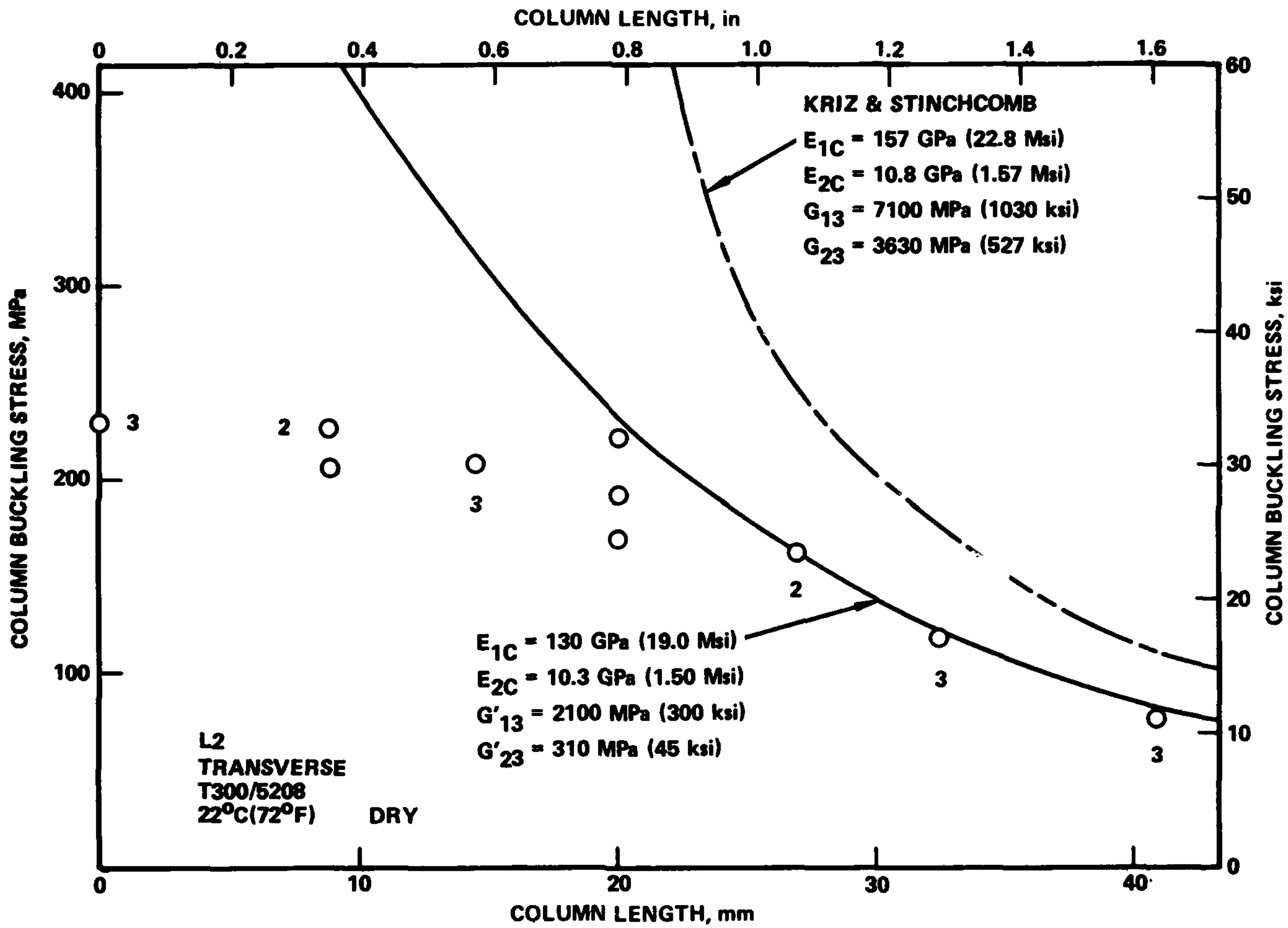


Figure 126. - Column analysis results for laminate L2T with values of G'_{13} and G'_{23} determined experimentally by Kriz and Stinchcomb.

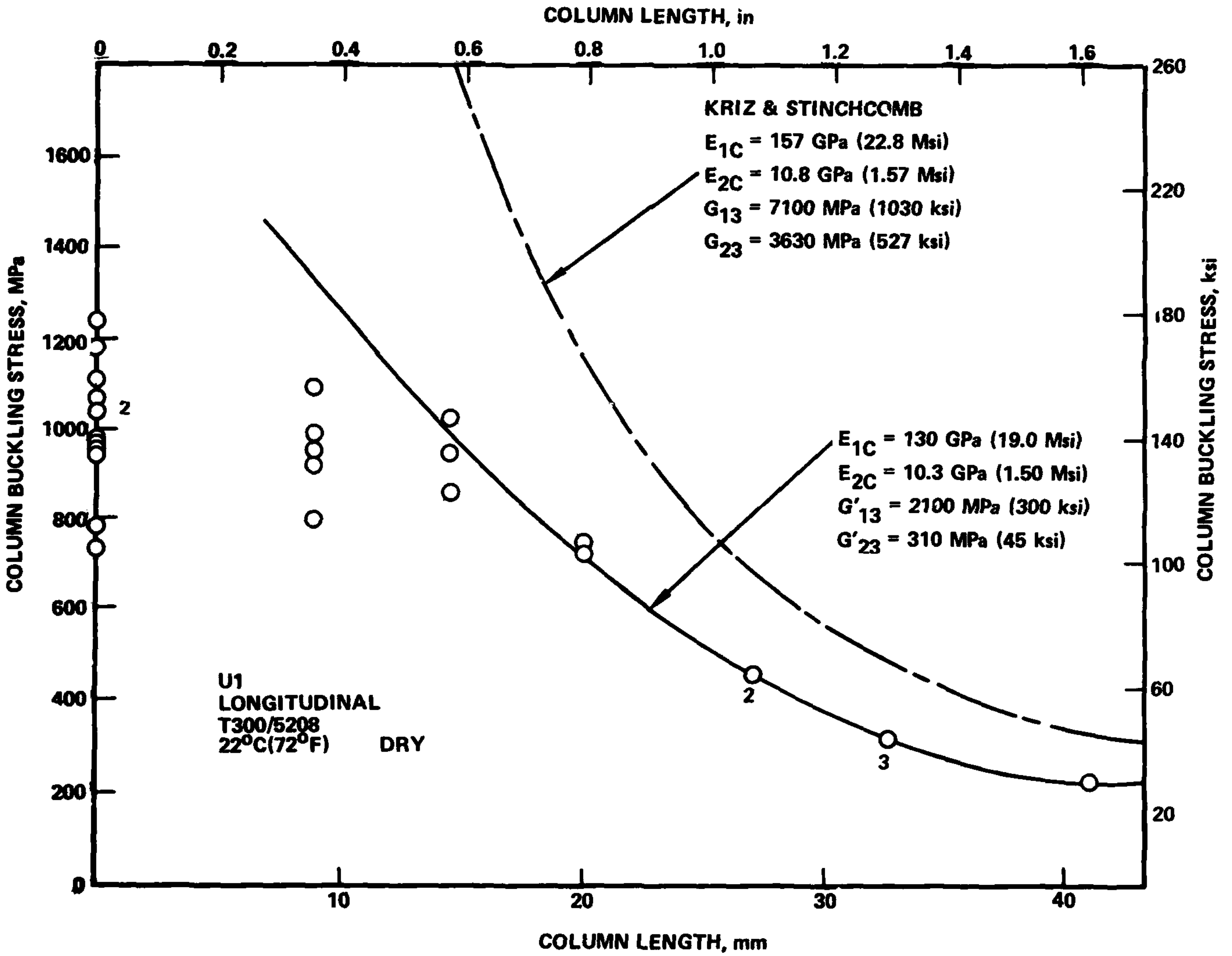


Figure 127. - Column analysis results for laminate U1L with values of G'_{13} and G'_{23} determined experimentally by Kriz and Stinchcomb.

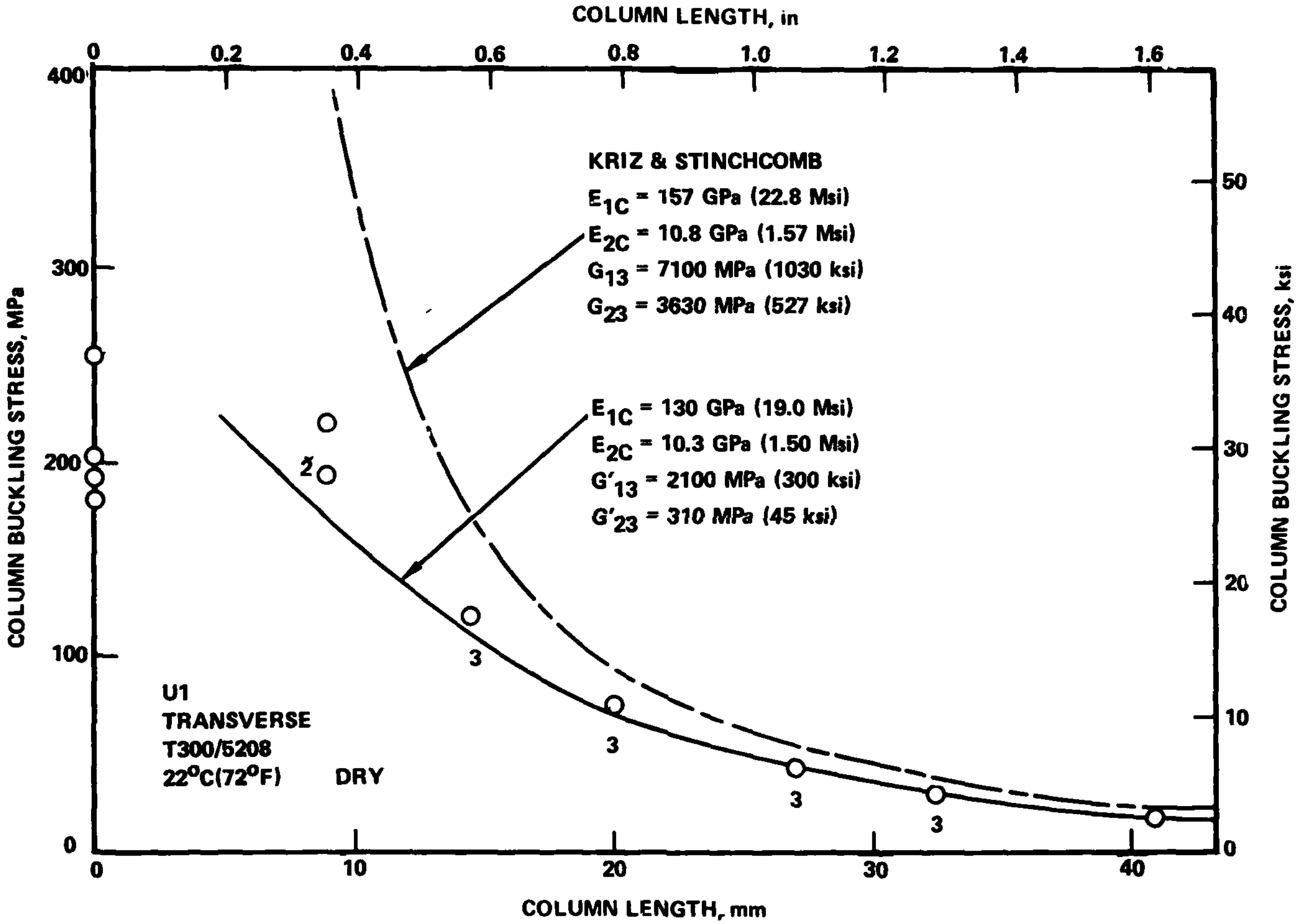


Figure 128. - Column analysis results for laminate U1T with values of G'_{13} and G'_{23} determined experimentally by Kriz and Stinchcomb.

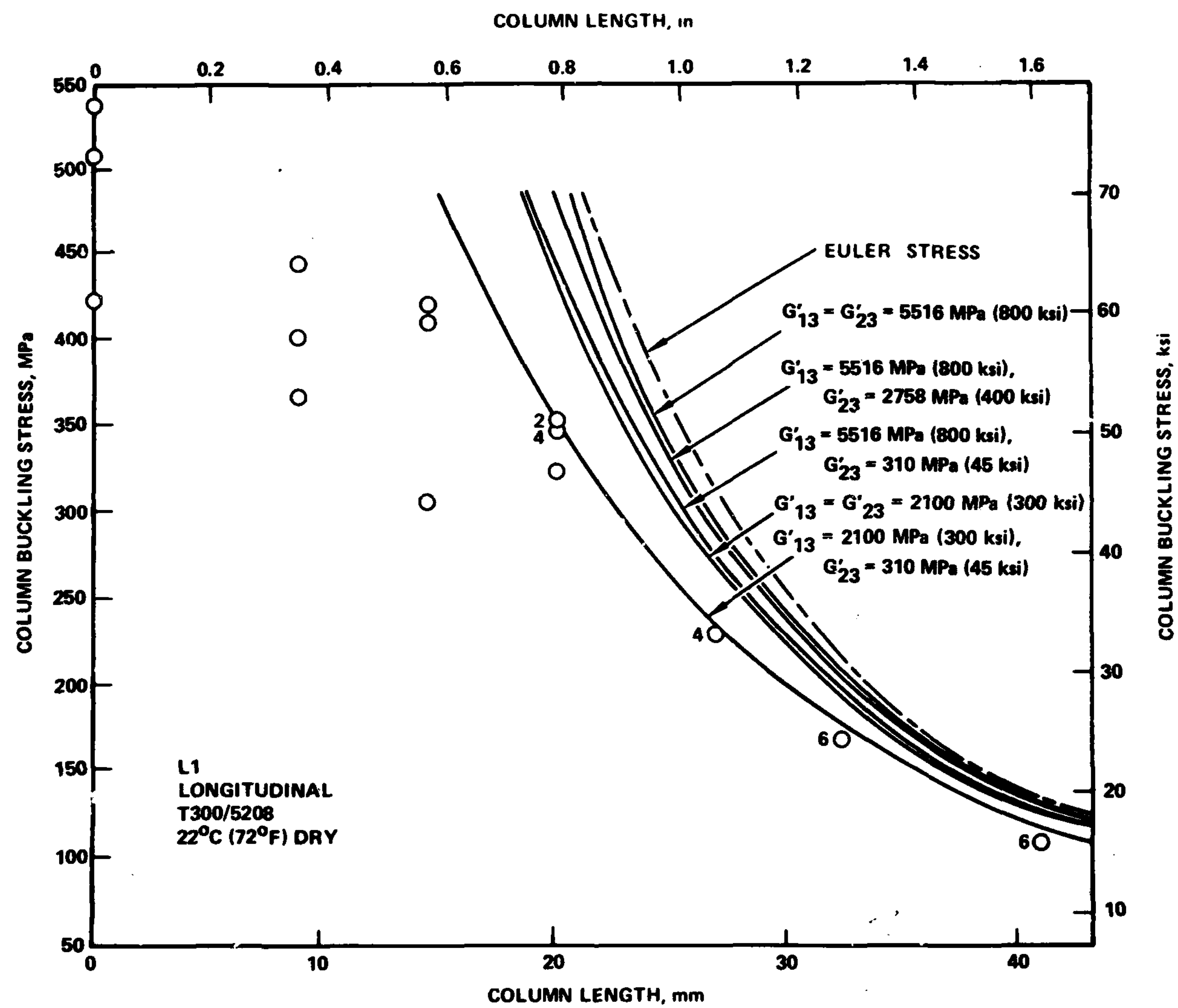


Figure 129. - Effect of variations in values of G'_{13} and G'_{23} on column analysis for laminate L1L.

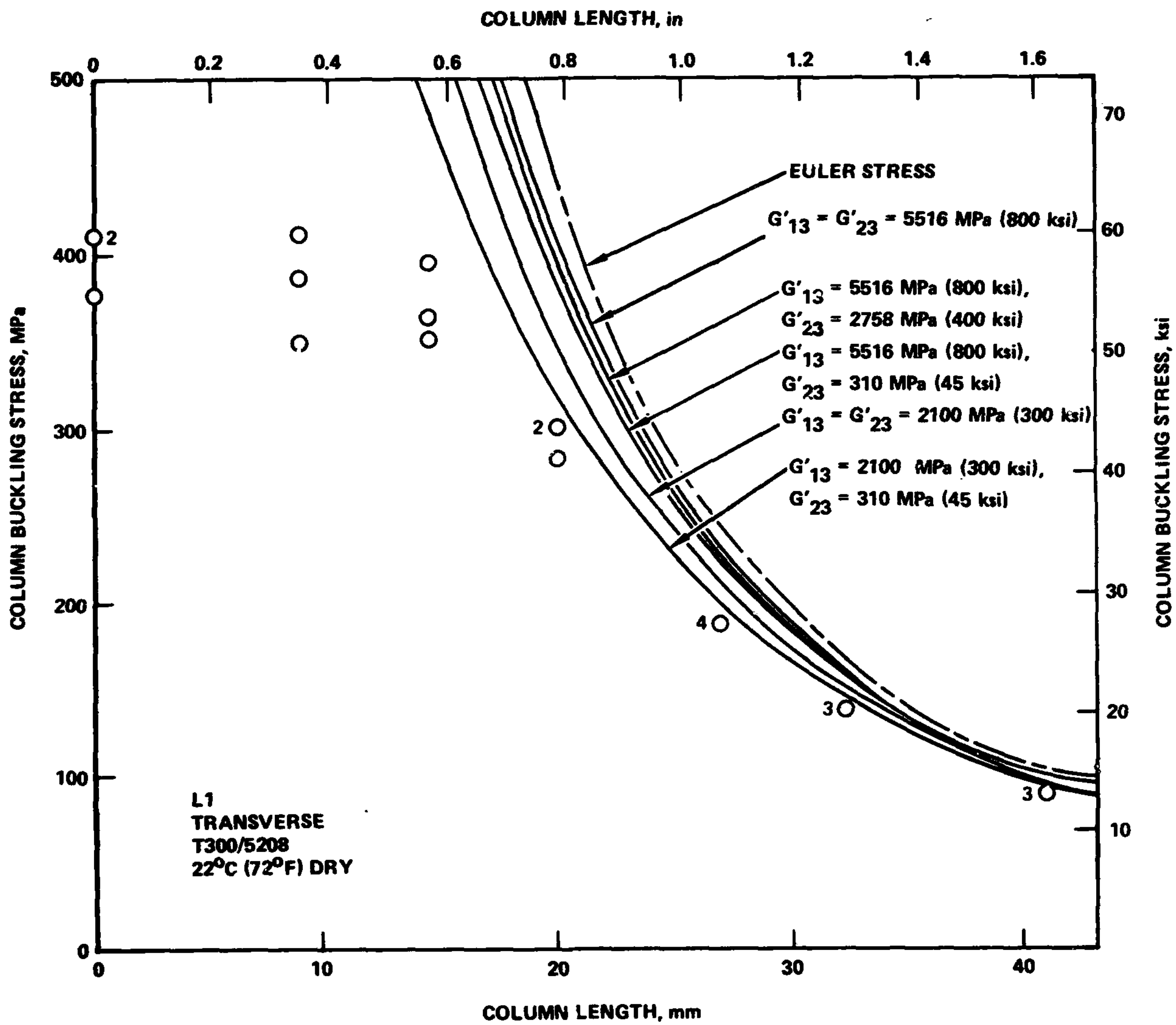


Figure 130. - Effect of variations in values of G'_{13} and G'_{23} on column analysis for laminate L1T.

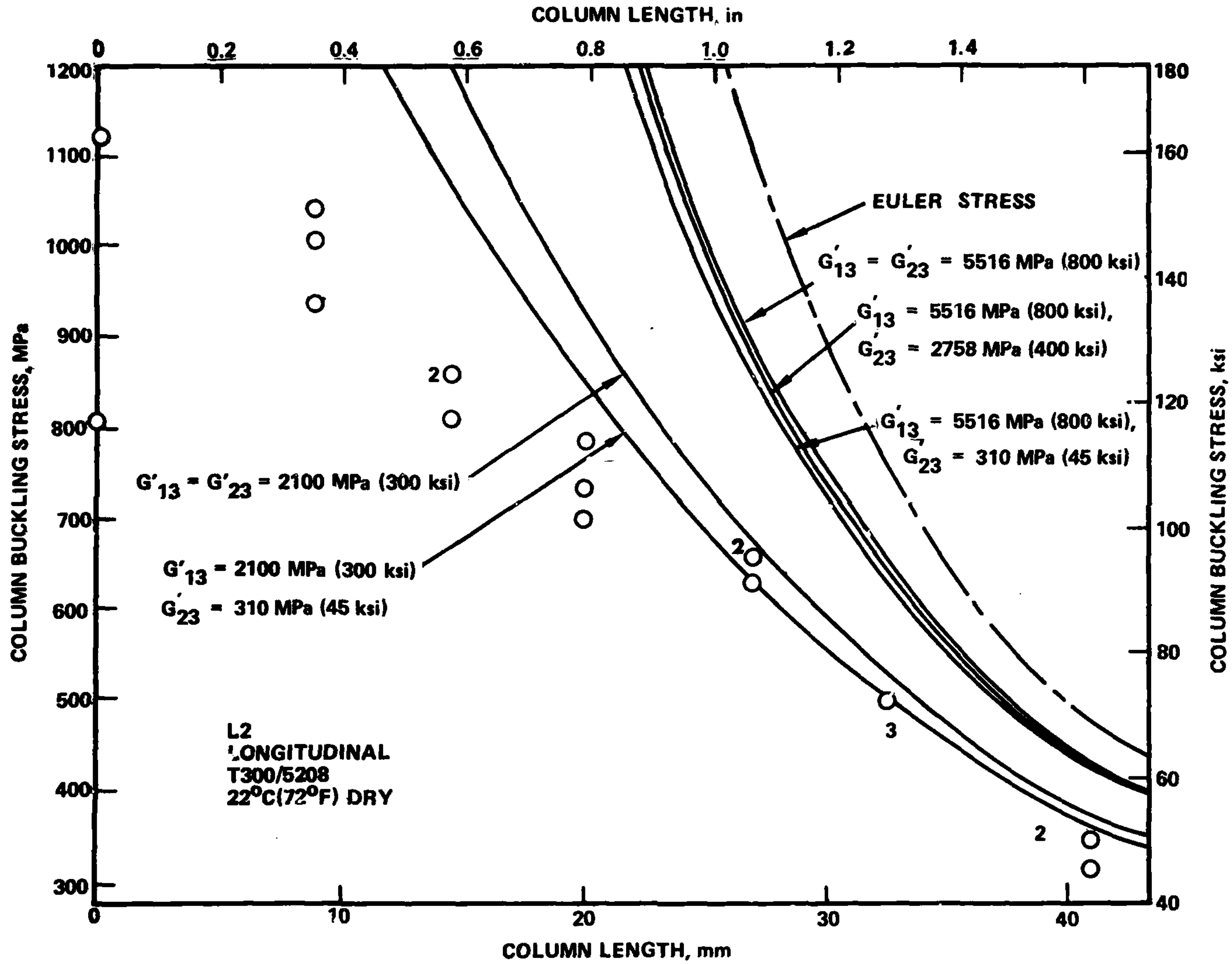


Figure 131. - Effect of variations in values of G'_{13} and G'_{23} on column analysis for laminate L2L.

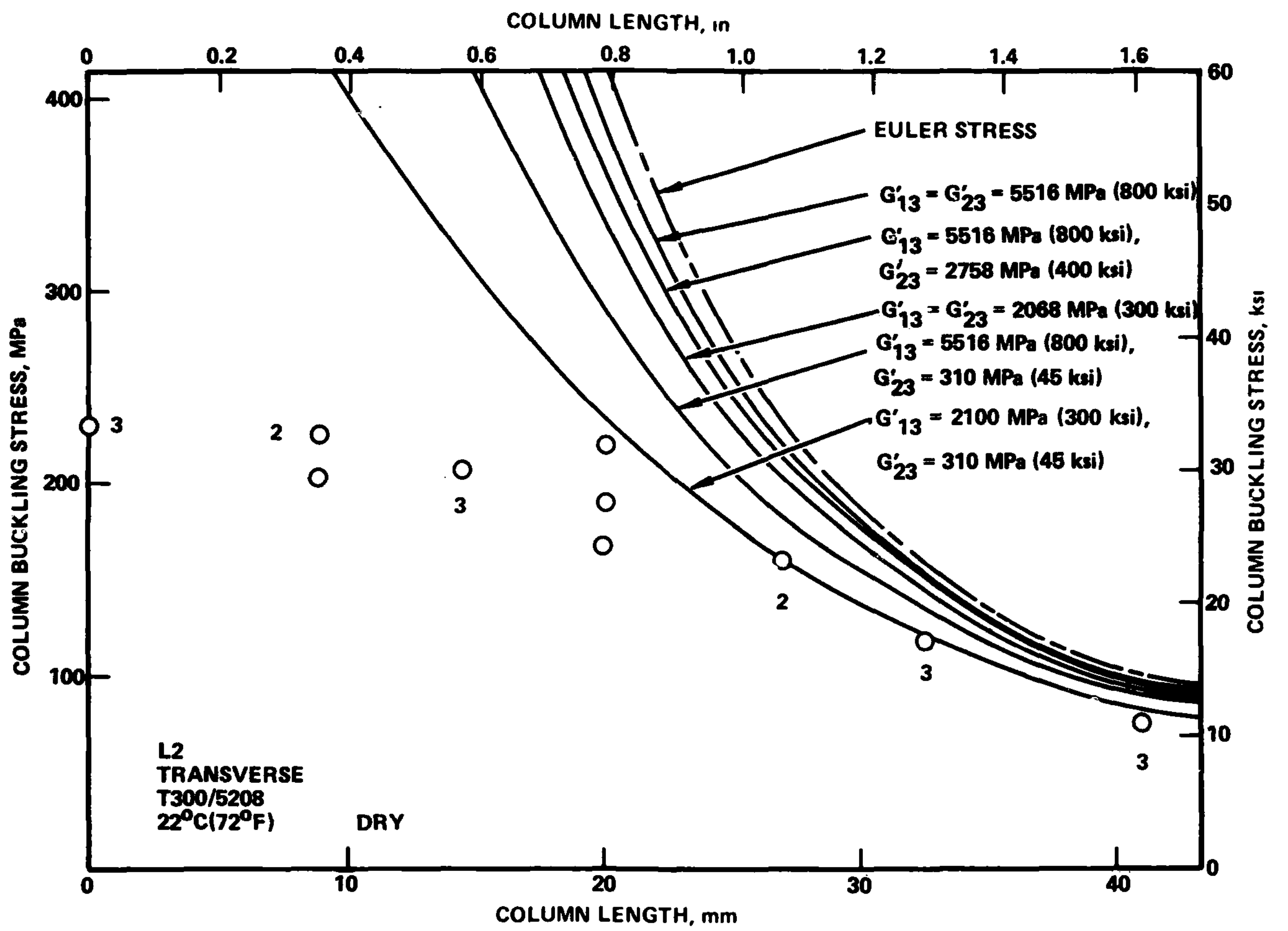


Figure 132. - Effect of variations in values of G'_{13} and G'_{23} on column analysis for laminate L2T.

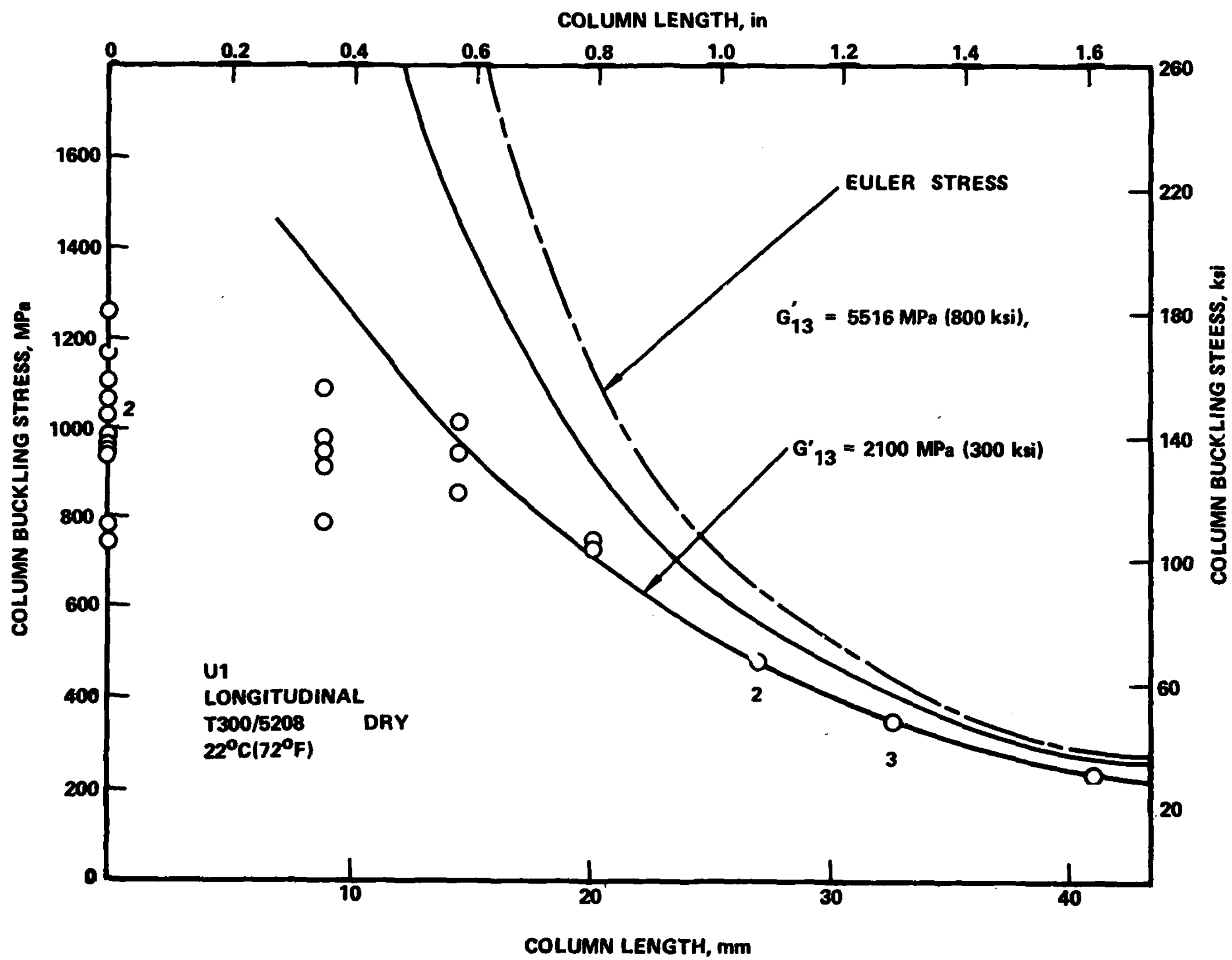


Figure 133. - Effect of variations in values of G'_{13} and G'_{23} on column analysis for laminate U1L.

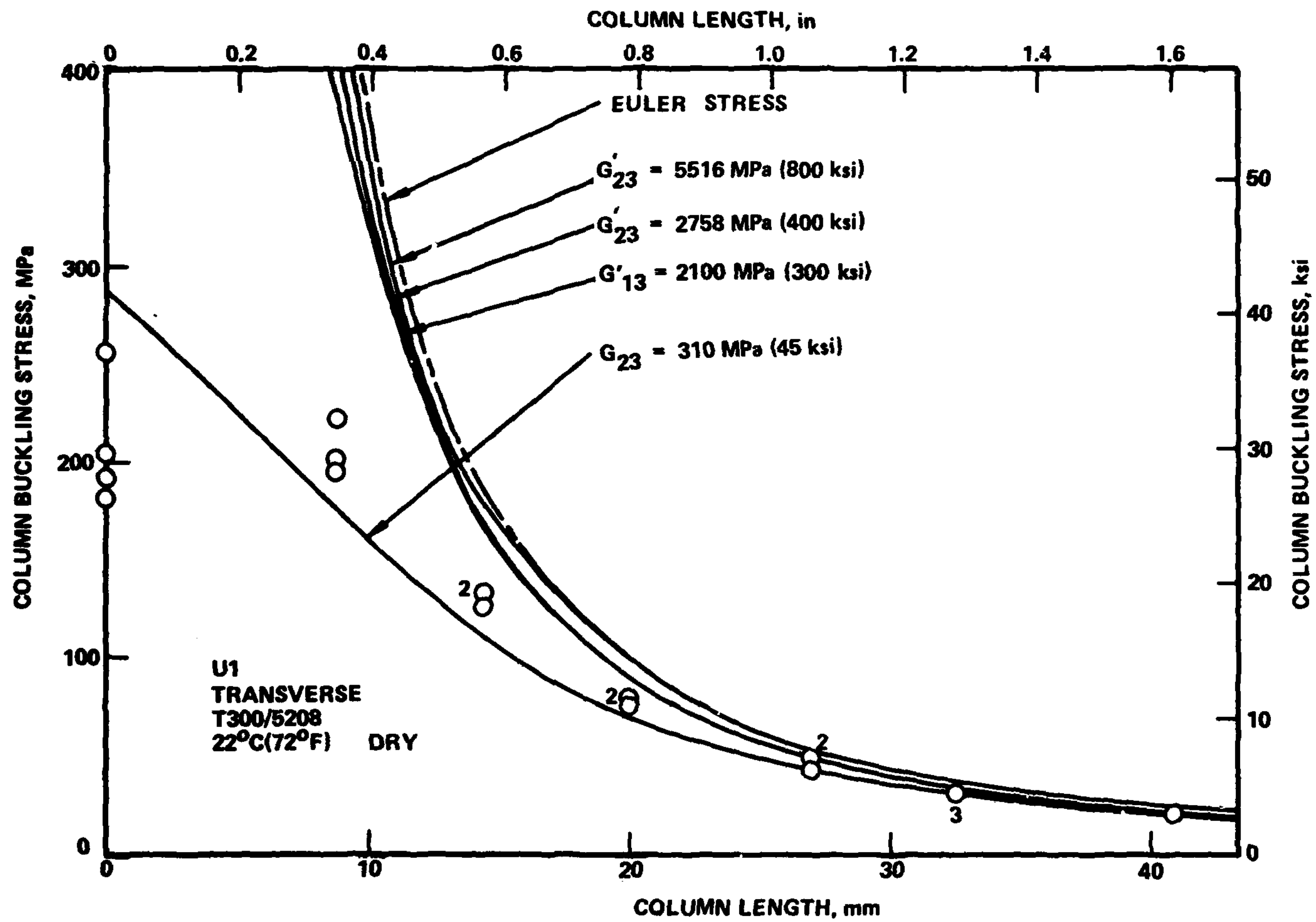


Figure 134. - Effect of variations in values of G'_{13} and G'_{23} on column analysis for laminate U1T.

test data. It can be seen that the selection of G'_{13} and G'_{23} to fit the column test data is quite unique. The two unknowns are determined by any two sets of data, such as Figures 129 and 130, or 130 and 131. However, the selected values fit four other sets of test data just as firmly. Additionally, these same values modified in a rational manner to provide G'_{13} and G'_{23} for thirty other test conditions, provide equally satisfactory fits to the test data obtained for those cases.

5.4 Approximate Method Using Shear Coefficient

An approximation to the results of the previous section may be obtained by using the weighted mean value of the ply stiffnesses for the laminate stiffness, and by estimating shear deformation with the shear coefficient method. The loss in rigor associated with the approximation is compensated by a considerable simplification in calculation.

The shear stiffness parameter S of Equation (1) is defined in Reference 8, page 133, as

$$S = KhG_{XZ} \tag{14}$$

where

K = shear coefficient (= 1/n of Reference 8)

G_{XZ} = effective transverse shear modulus of laminate

The approximate method consists simply of using S from Equation (14) in Equation (11), instead of S_p as derived by Equation (13).

For this approximation, the laminate is represented as being transversely homogeneous with a shear modulus G_{XZ} of:

$$G_{XZ} = \frac{1}{h} \sum_{k=1}^{n} \left[G'^{(k)}_{13} h_k \cos^2 \theta_k + G'^{(k)}_{23} h_k \sin^2 \theta_k \right] \tag{15}$$

This determination ignores the requirement (observed in Reference 10 and in the preceding section) that the shear stress acting on any one ply at the ply interface must be identically reacted by the shear stress on the face of the adjacent ply.

The shear coefficient K represents a further simplifying approximation, which provides for the effect of the loading configuration on the overall shear deformation. The shear coefficient was first used by Timoshenko in Reference 14 in developing an analysis for the effect of shear deformation and rotary inertia on the frequency of transverse vibrations of a bar of isotropic material. Various derivations of K for both static and dynamic loading conditions, for isotropic, orthotropic, and laminate materials, as well as extensions and applications to the theory of plates, can be found in the literature (for example, References 14 through 19). The basic assumptions are those of beam theory and the Kirchhoff hypotheses, which ignore out-of-plane warping of the cross-section that occurs when shear is present. Values of K derived for isotropic material under various loading conditions can be found in the literature (as well as some derived with no regard to configuration) and these have been applied with some success to orthotropic materials (e.g., Reference 20).

Column deflection, like that of a vibratory beam, produces a sinusoidal distribution of shear load, but the phase relationship with respect to the bending moment distribution is displayed $\pi L/2$ from that arising from inertial forces. Nevertheless, the Mindlin shear coefficient $K = \pi^2/12$, which was derived for the thickness-shear mode of vibratory deflection (Reference 16), provides good agreement with the laminate column analysis of the previous section.

A comparison of the results of the laminate column analysis and the approximate method is presented for representative cases in Figures 135 - 138. The values of G_{13} and G_{23} used to derive G_{XZ} in the approximate method are those which were determined as a fit to the column test data in the previous section; the Mindlin shear coefficient is used for K. On Figures 135 - 138 it is seen that the simple approximate method fits the test data quite well.

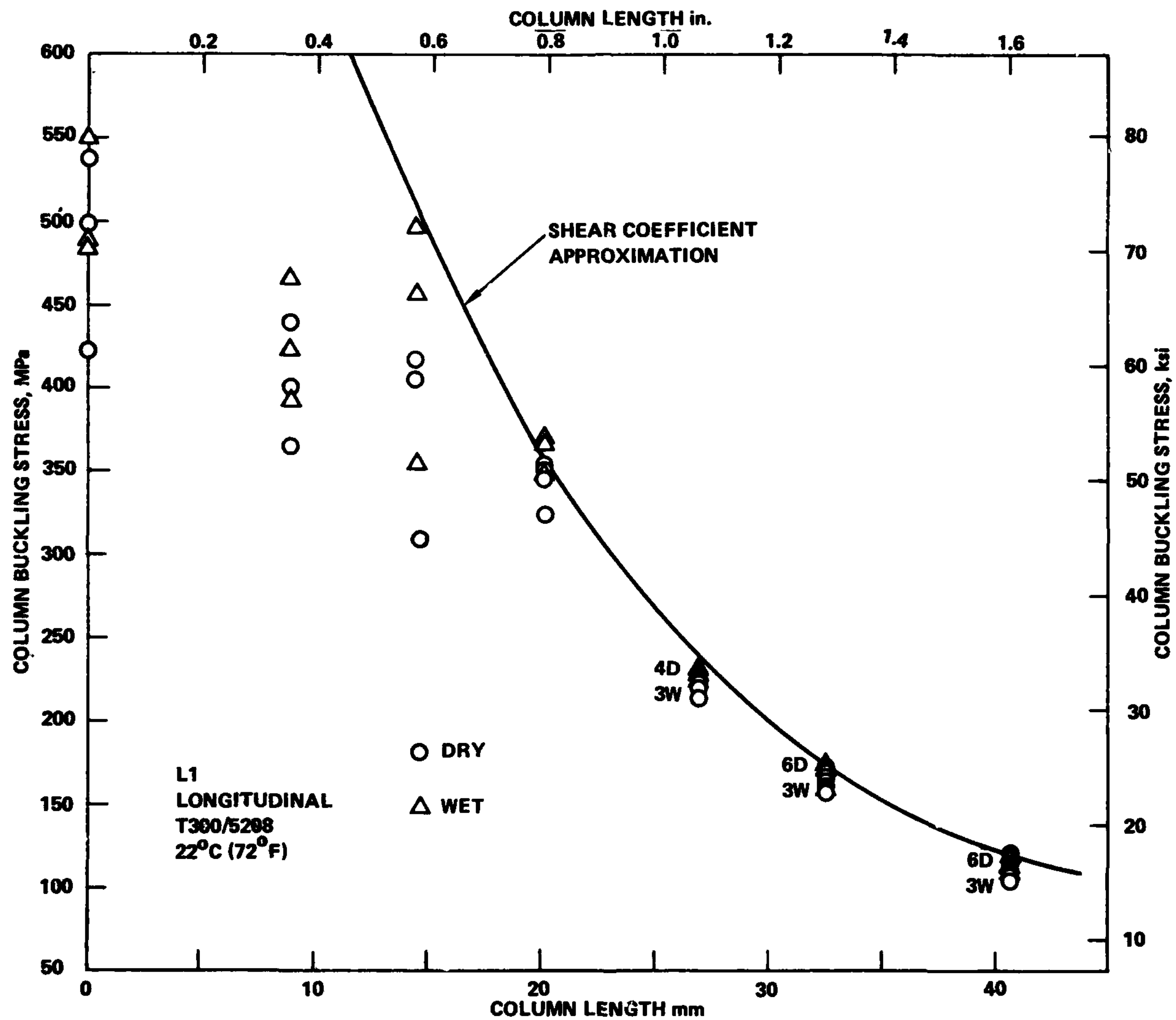


Figure 135. - Column analysis results using shear coefficient approximation for laminate L1L.

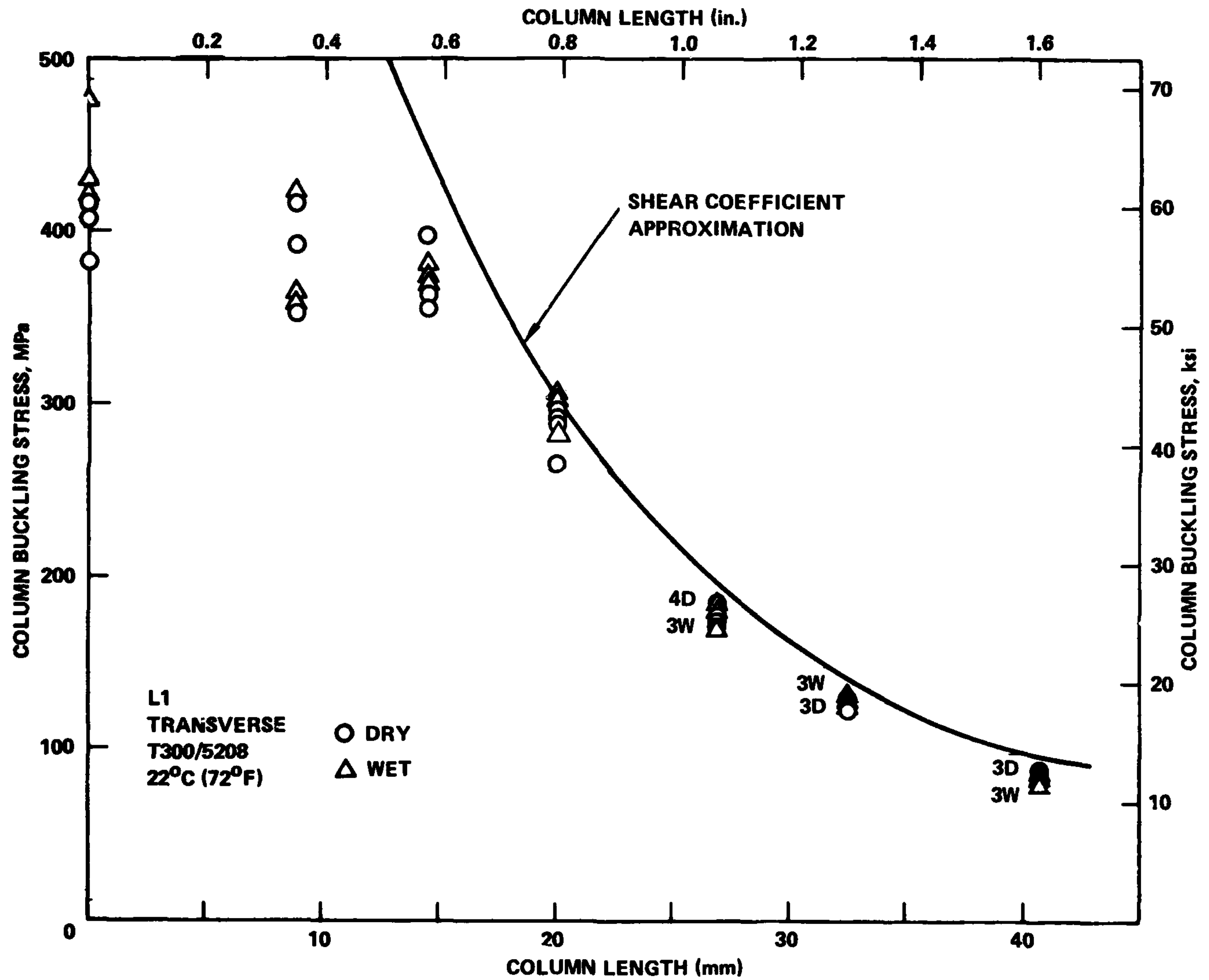


Figure 136. - Column analysis results using shear coefficient approximation for laminate L1T.

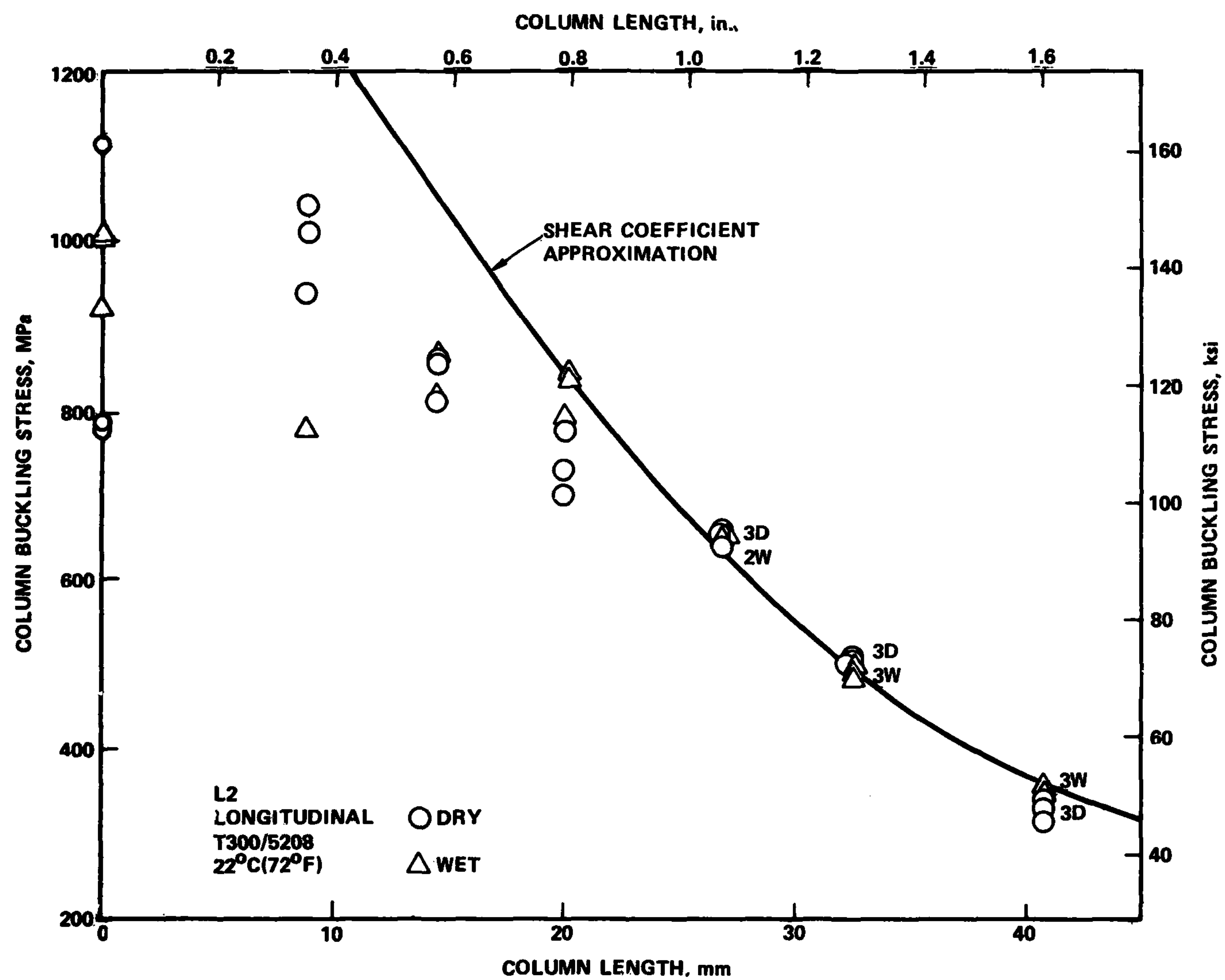


Figure 137. - Column analysis results using shear coefficient approximation for laminate L2L.

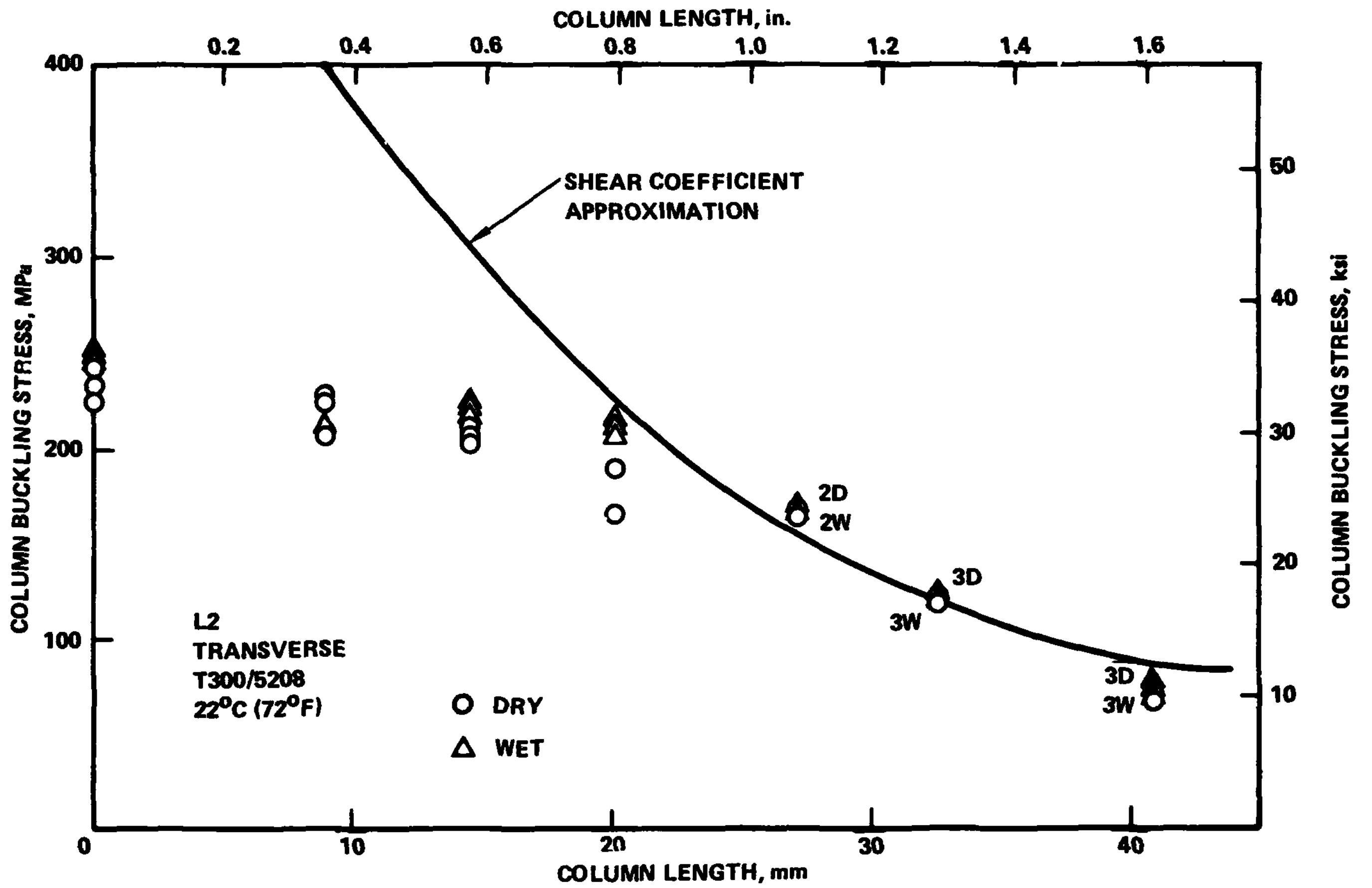


Figure 138. - Column analysis results using shear coefficient approximation for laminate L2T.

5.5 Effects of Drying, Reconditioning, Non-Uniform Moisture Distribution, and Microcracks on the Column Curves

Supplementary test investigations of the effects of a number of special environmental exposure conditions prior to column testing are documented above in Sections 4.8, 4.9 and 4.10. To assist in the evaluation of these effects, the column test data obtained are displayed in the conventional form for comparison with the baseline data and with the analytical curves developed in this section.

Figures 139 - 144 present the column data obtained on specimens which were first dried to less than 0.1 weight percent moisture, and those which were first dried and then reconditioned to the "wet" condition. Theoretically predicted column curves, as well as the scatter bands of the baseline data, are included for comparison. Column behavior of the dried, and of the dried and reconditioned specimens, is essentially the same as that of the baseline specimens.

In Figures 145 through 152, the column test data obtained with specimens having non-uniform moisture distributions are compared with baseline data and with analytical curves. Significant differences are noted in certain of the cases: for example, column strengths of the AS/3501 specimens of laminate L2 tested at 0° to the laminate axis appear to have been reduced substantially by non-uniformity of moisture distribution (Figure 146), and the scatter appears larger with non-uniform moisture distribution for the AS/3501 material. However, results with the other laminates do not reinforce these comparisons. From these test data, the only effect which might possibly be attributed to a non-uniform moisture distribution is an increase in the test scatter.

Baseline column test data obtained with the supplementary batch material (SY) are plotted in Figures 153 - 155, for comparison with the analytical column curves. The excellent agreement substantiates the conclusion drawn in Section 4, that there was no difference in column performance between batch TY and SY material. Results obtained with specimens which were

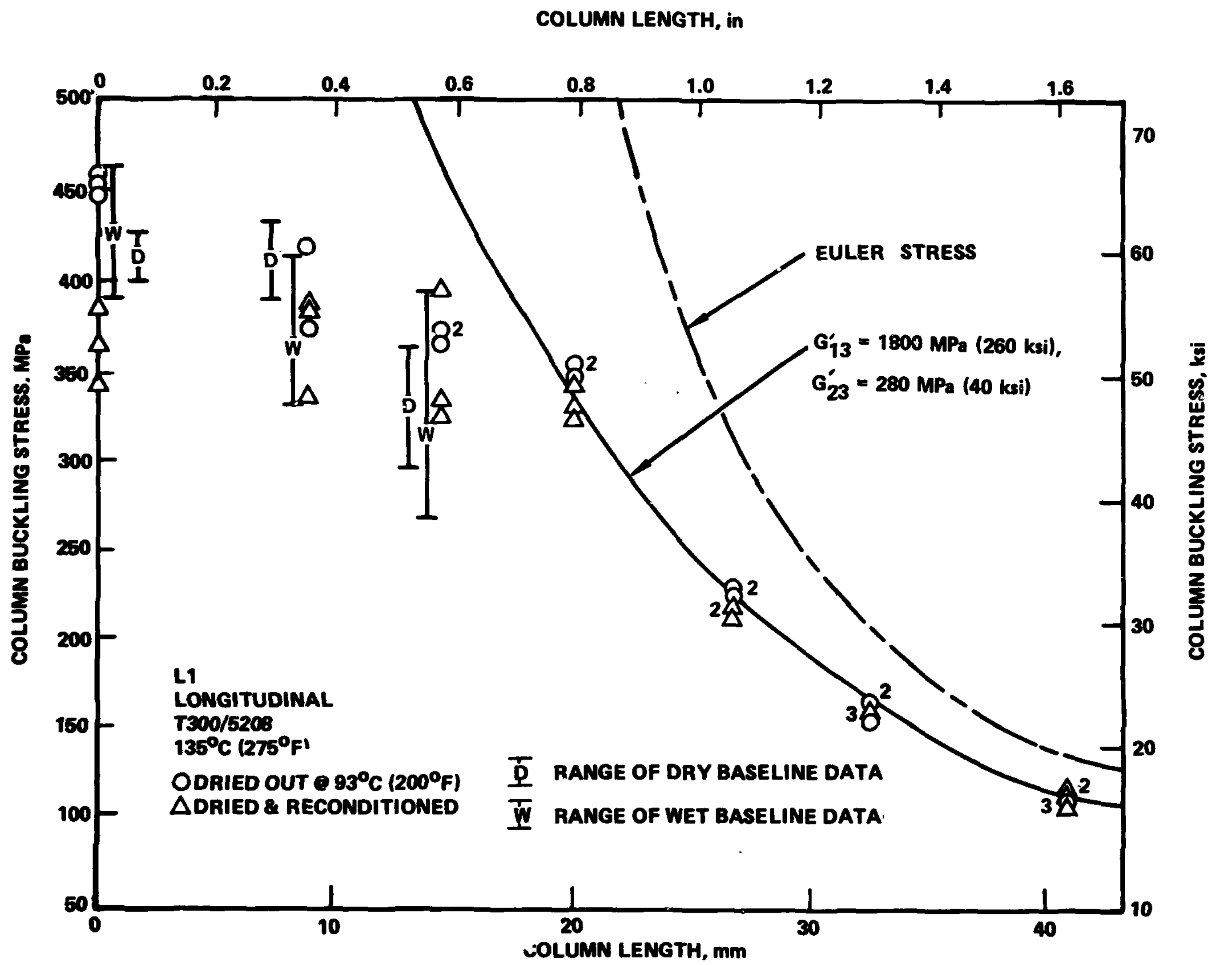


Figure 139. - Effect of drying and reconditioning on column buckling behavior of laminate L1L.

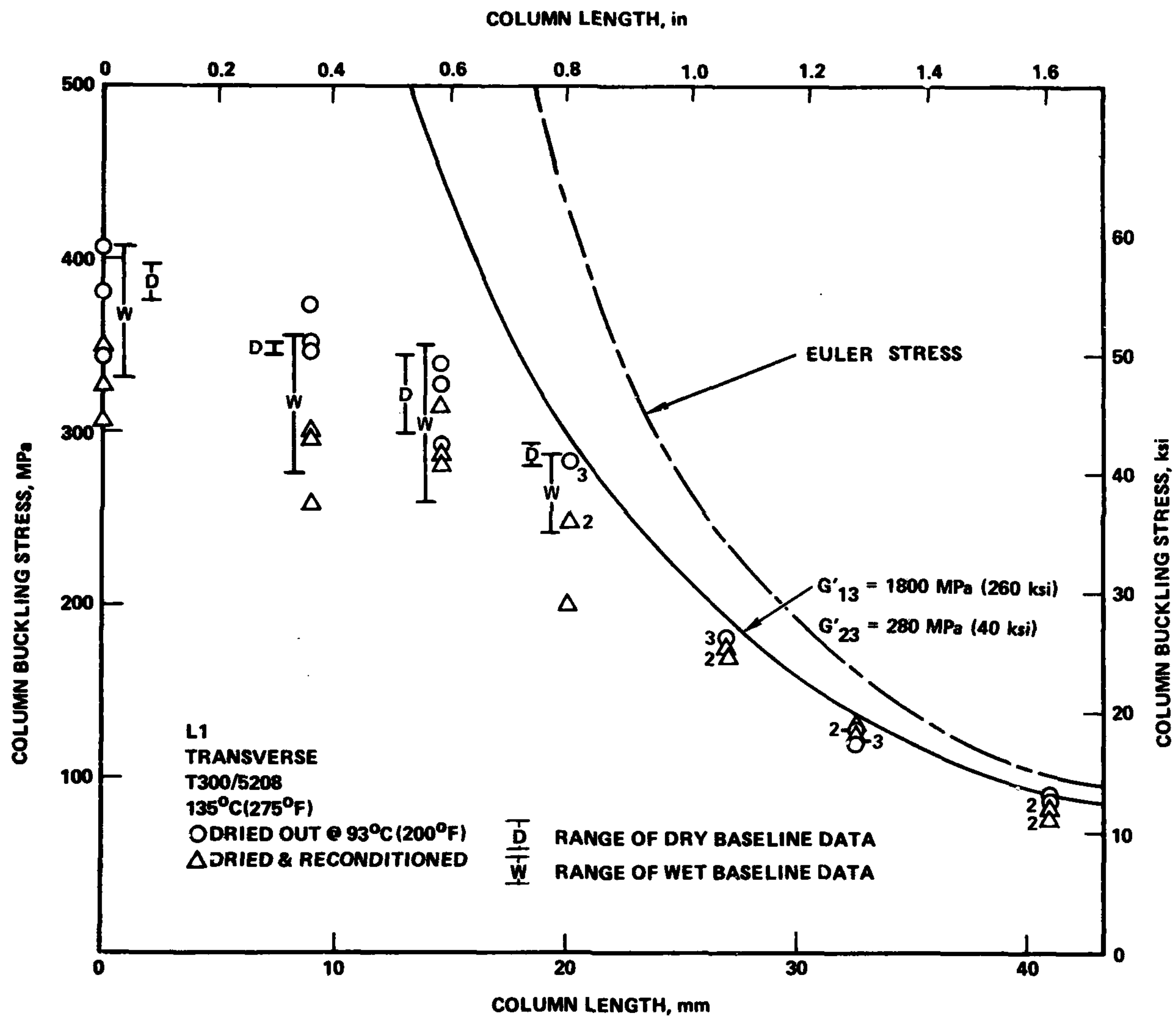


Figure 140. - Effect of drying and reconditioning on column buckling behavior of laminate L1T.

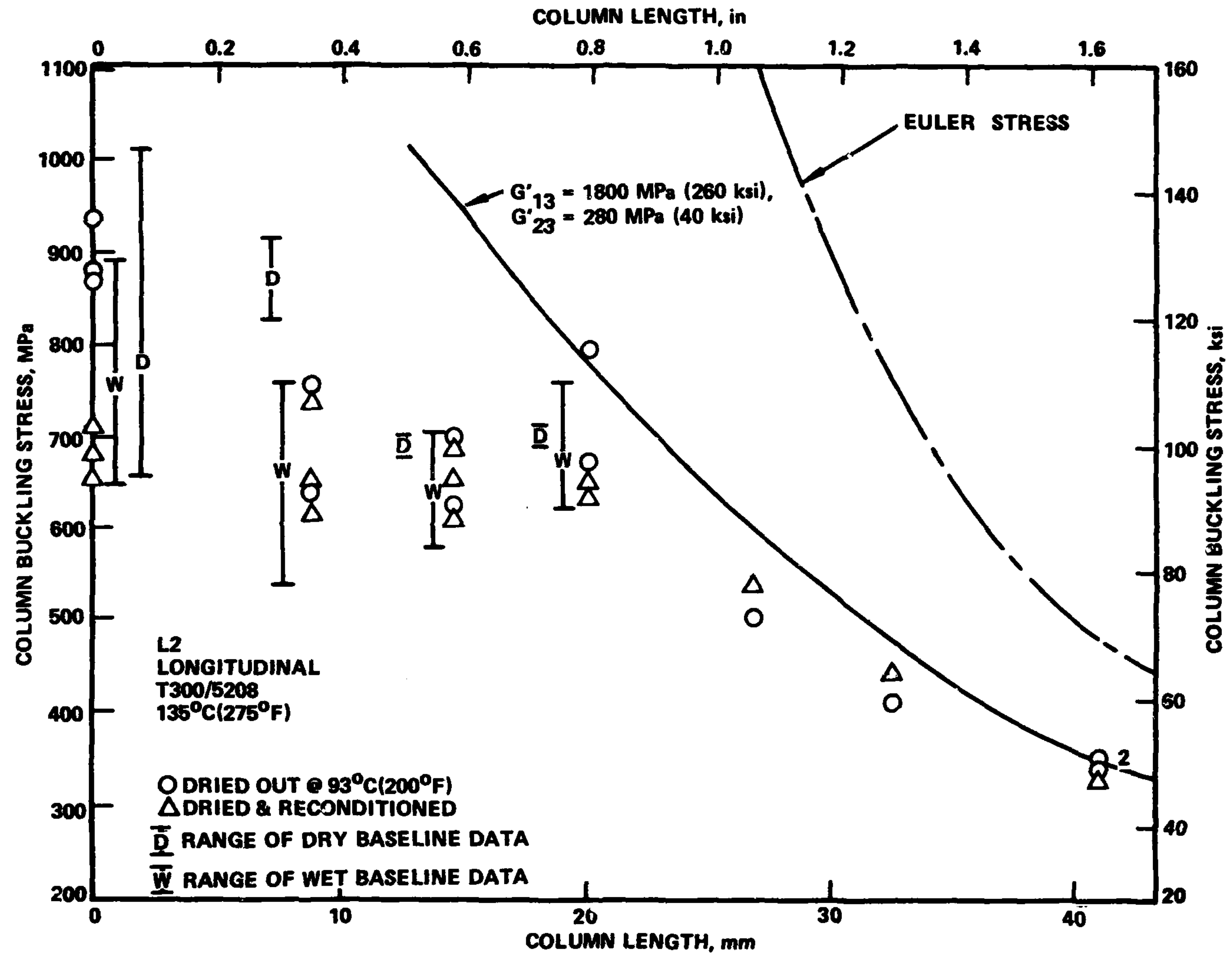


Figure 141. - Effect of drying and reconditioning on column buckling behavor of laminate L2L.

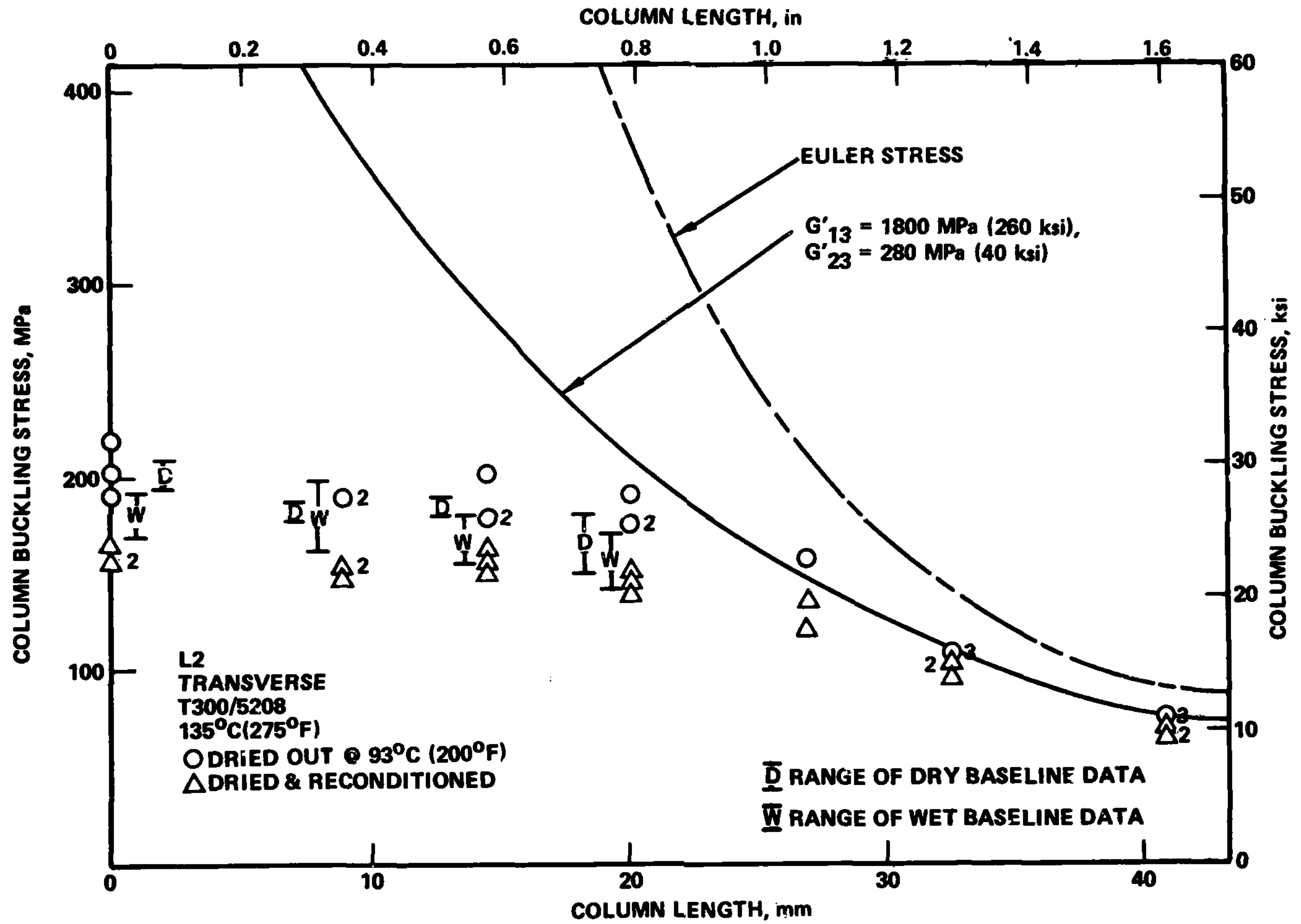


Figure 142. - Effect of drying and reconditioning on column buckling behavor of laminate L2T.

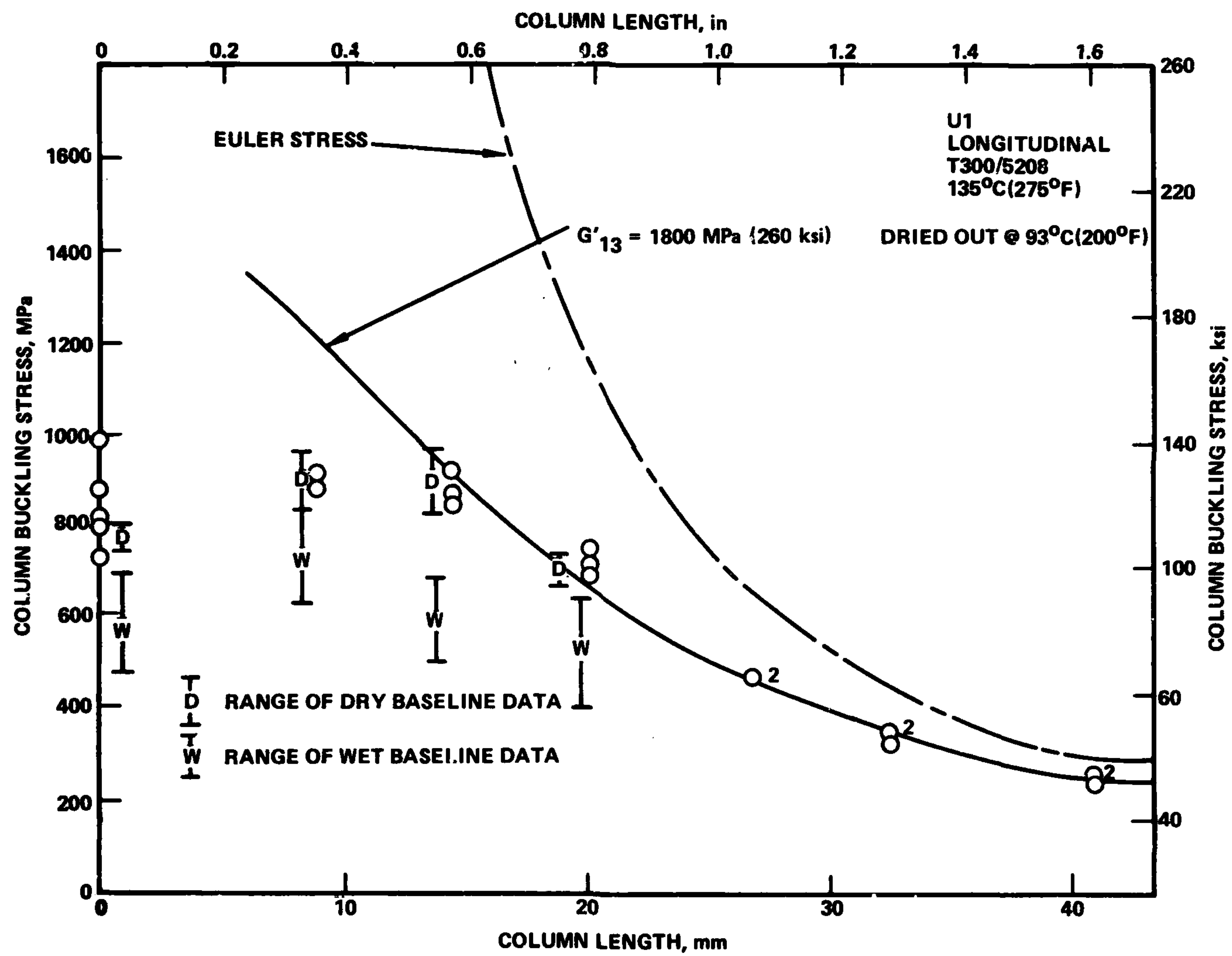


Figure 143. - Effect of drying and reconditioning on column buckling behavior of laminate U1L.

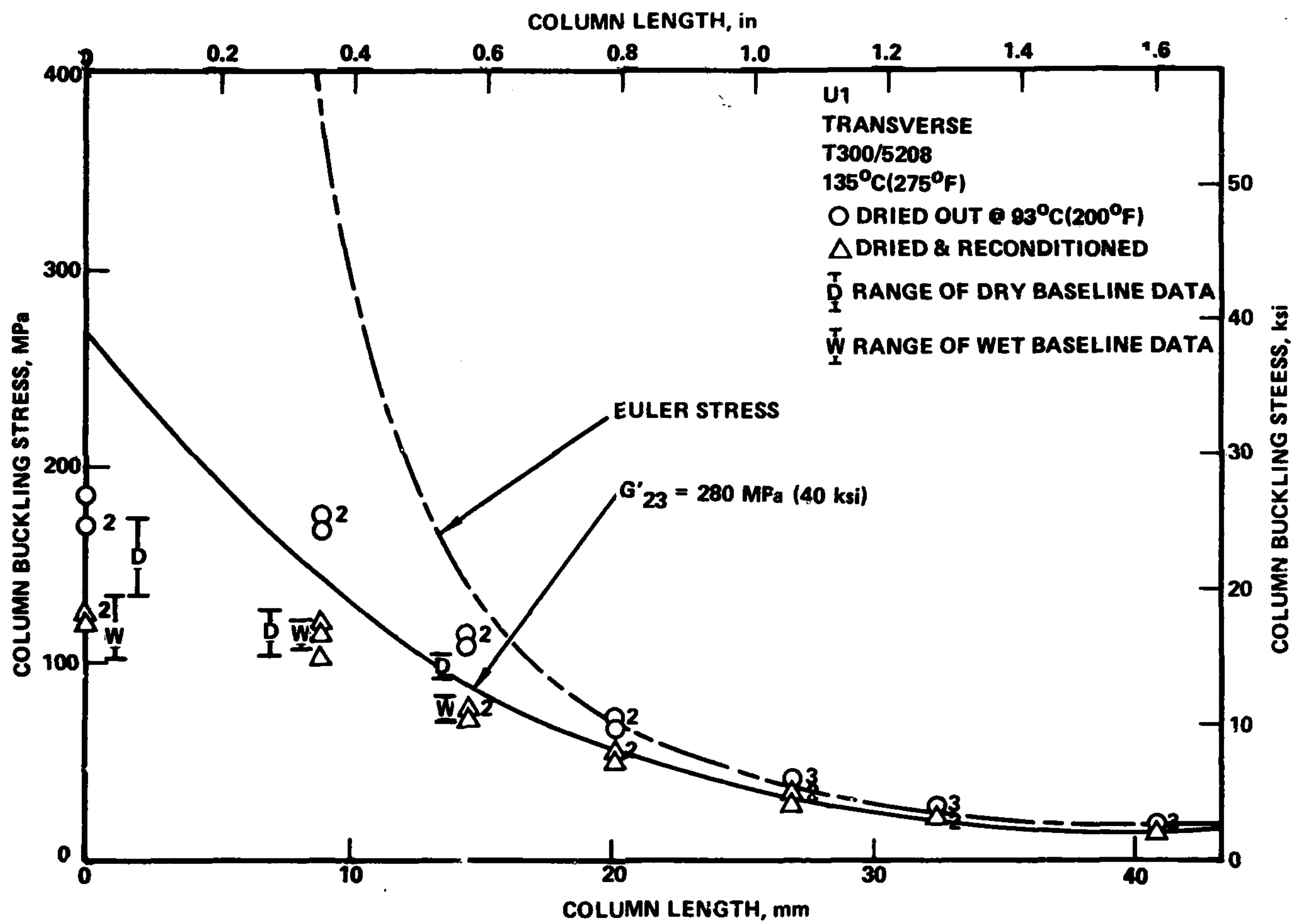


Figure 144. - Effect of drying and reconditioning on column buckling behavior of laminate U1T.

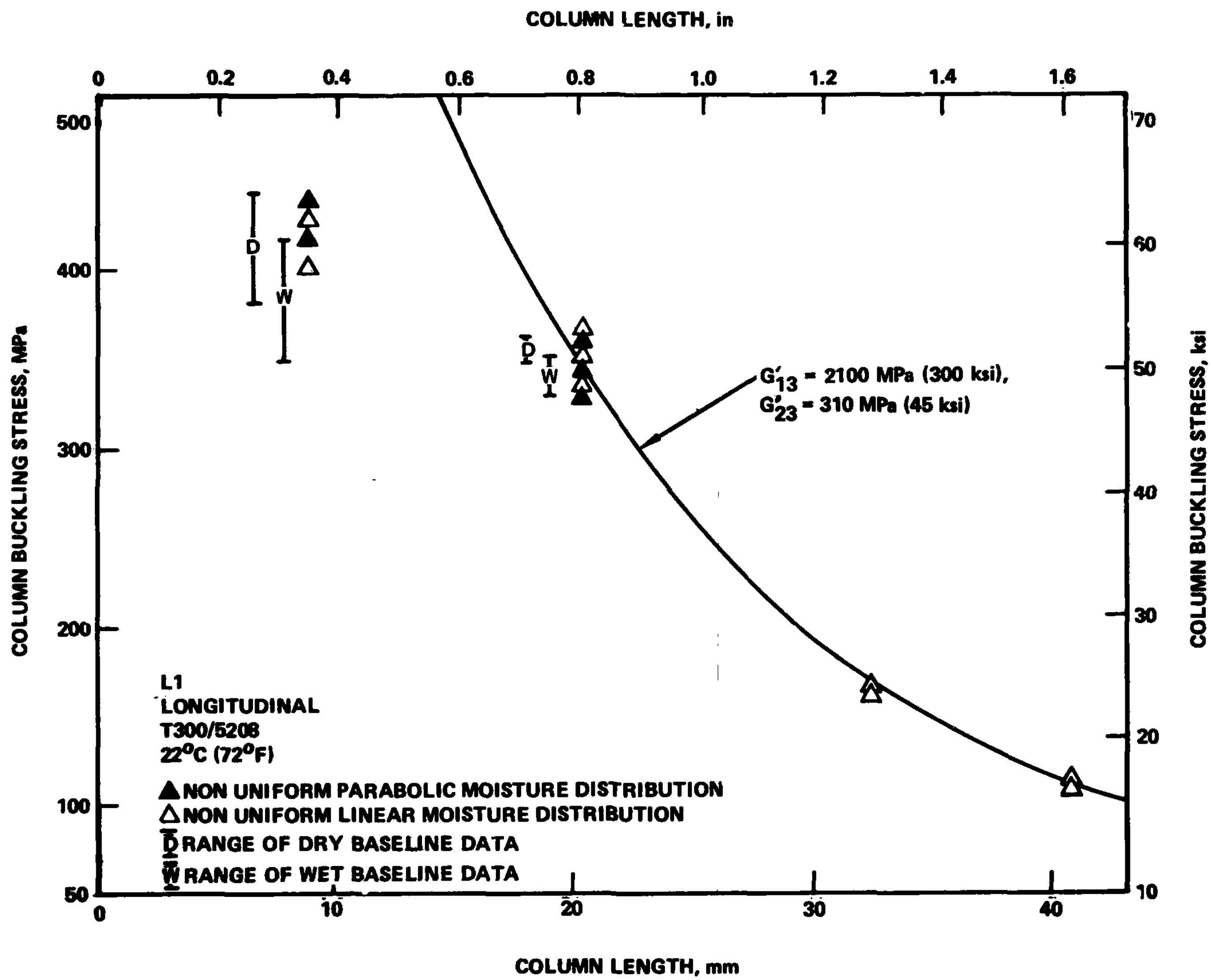


Figure 145. - Effect of non-uniform moisture distributions on column buckling behavior of T300/5208 Laminate L1L at 22°C.

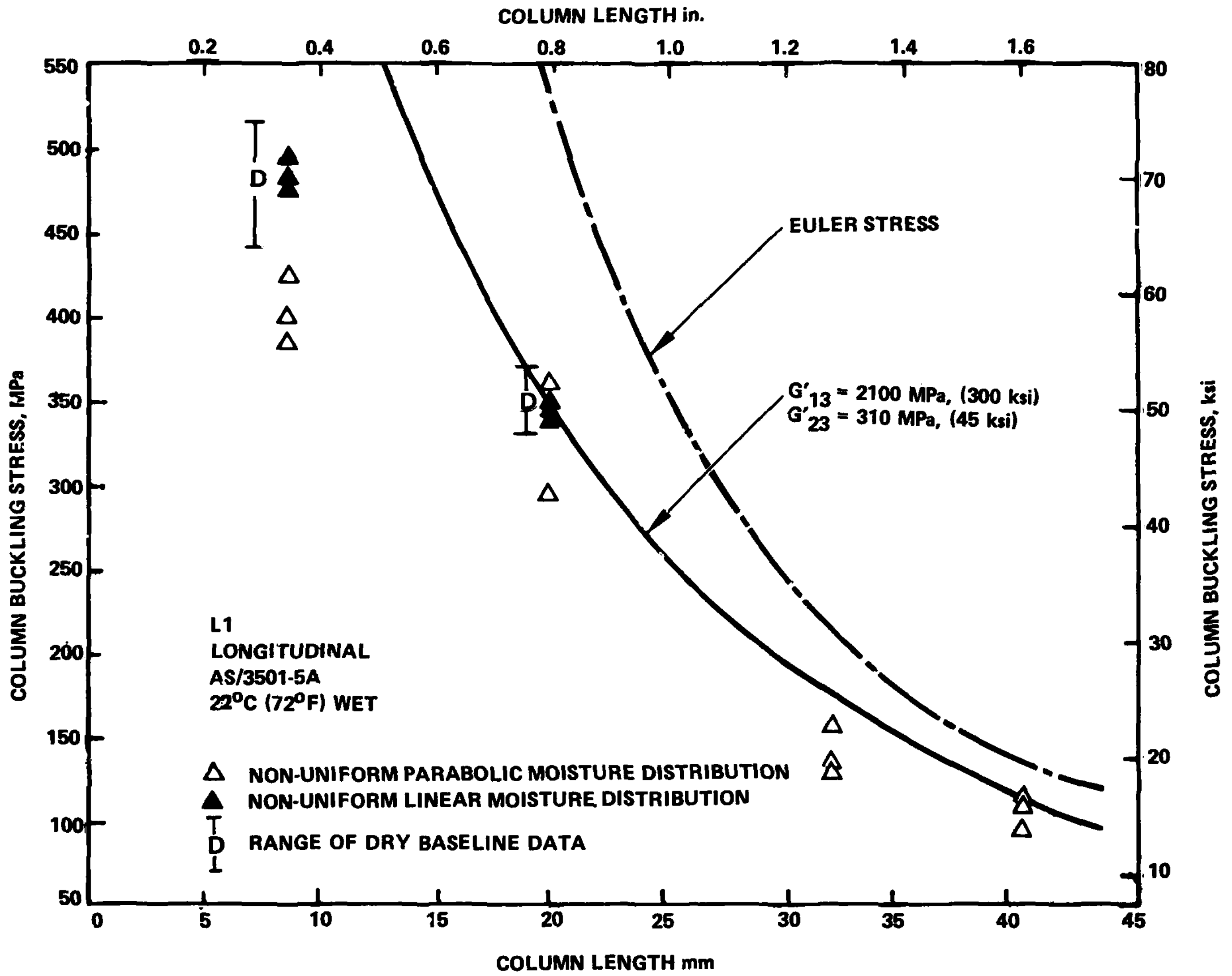


Figure 146. - Effect on non-uniform moisture distributions on column buckling behavior of AS/3501-5A laminate L1L at 22°C.

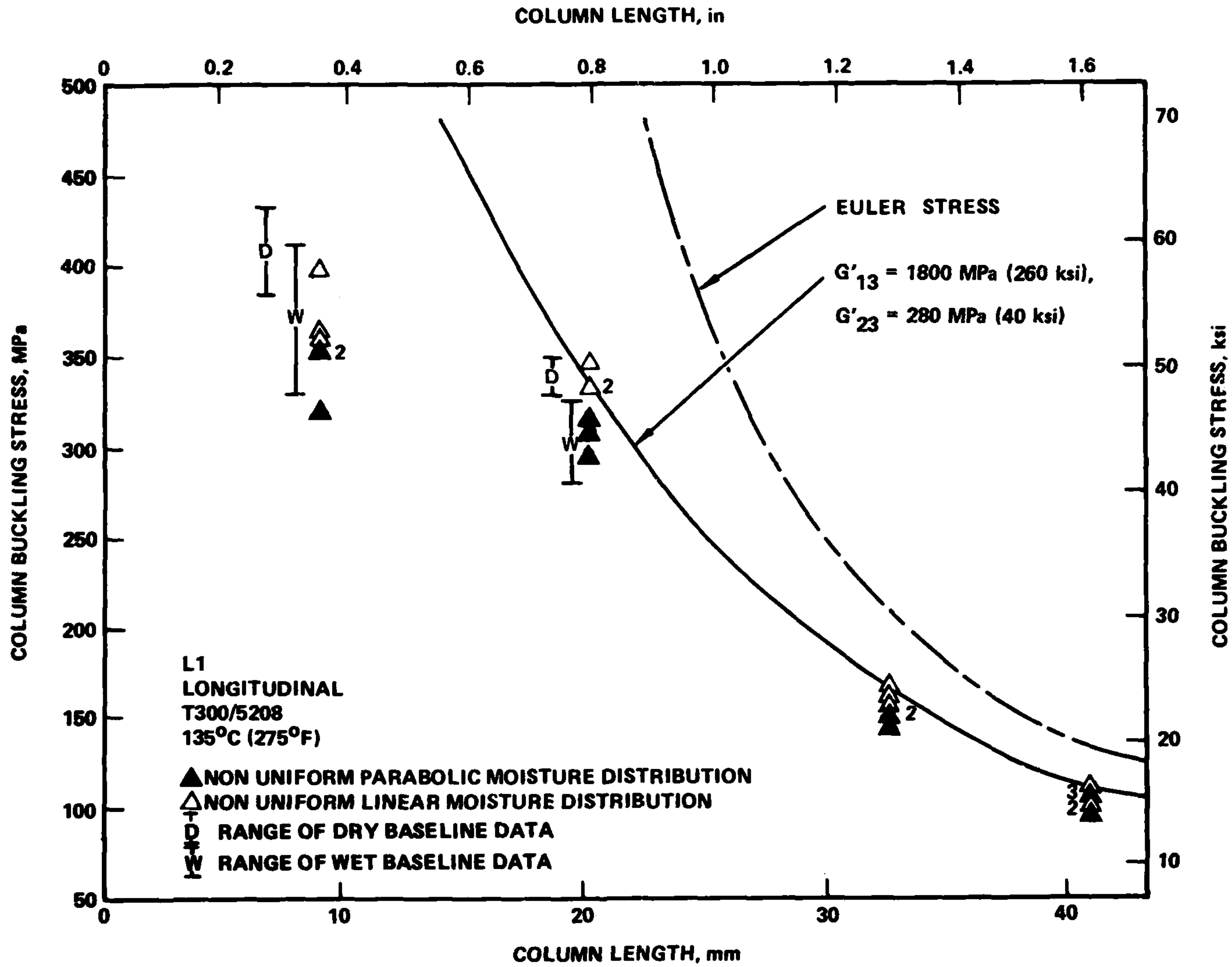


Figure 147. - Effect of non-uniform moisture distributions on column buckling behavior of T300/5208 laminate L1L at 135°C.

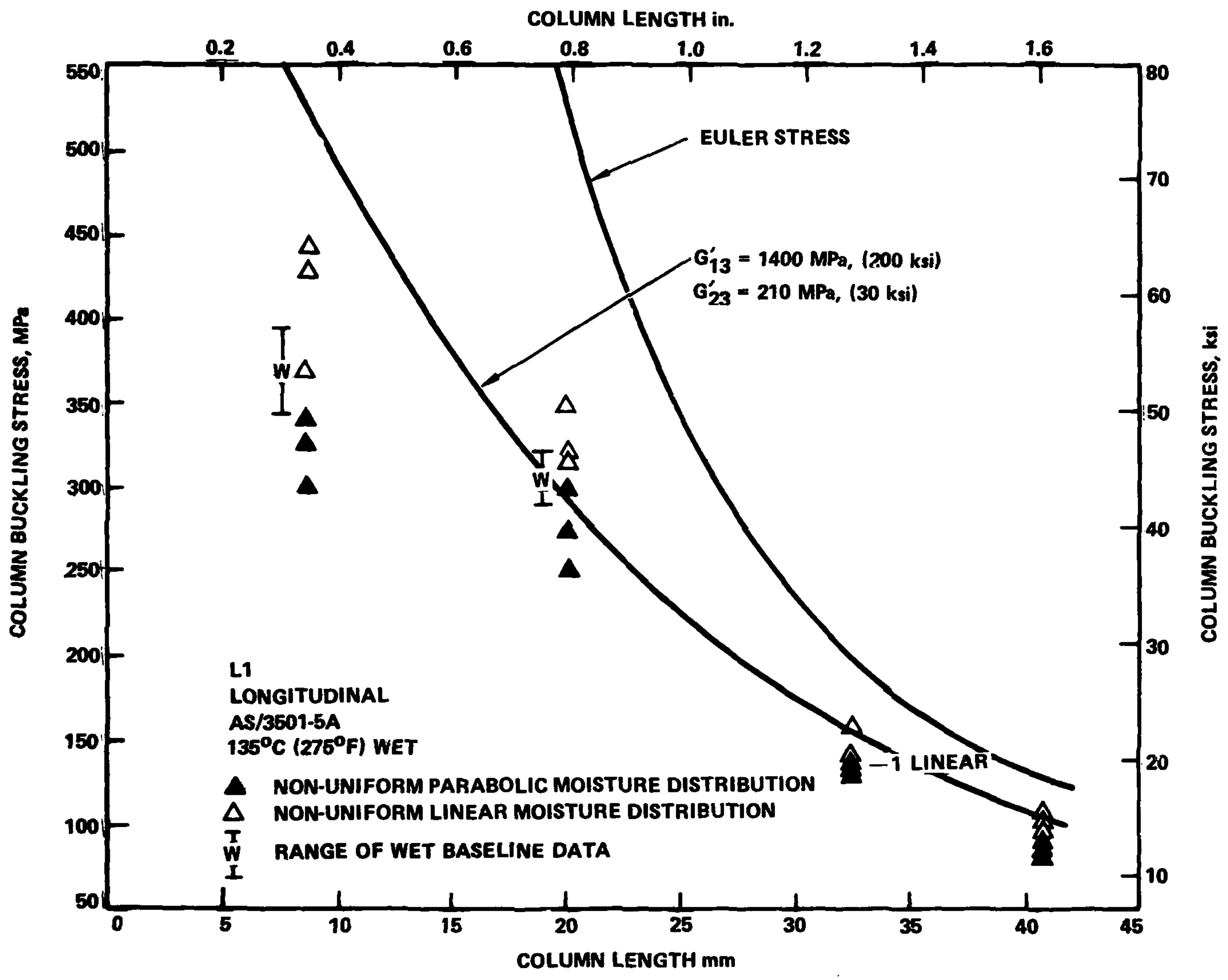


Figure 148. - Effect of non-uniform moisture distributions on column buckling behavior of AS/3501-5A laminate L1L at 135°C.

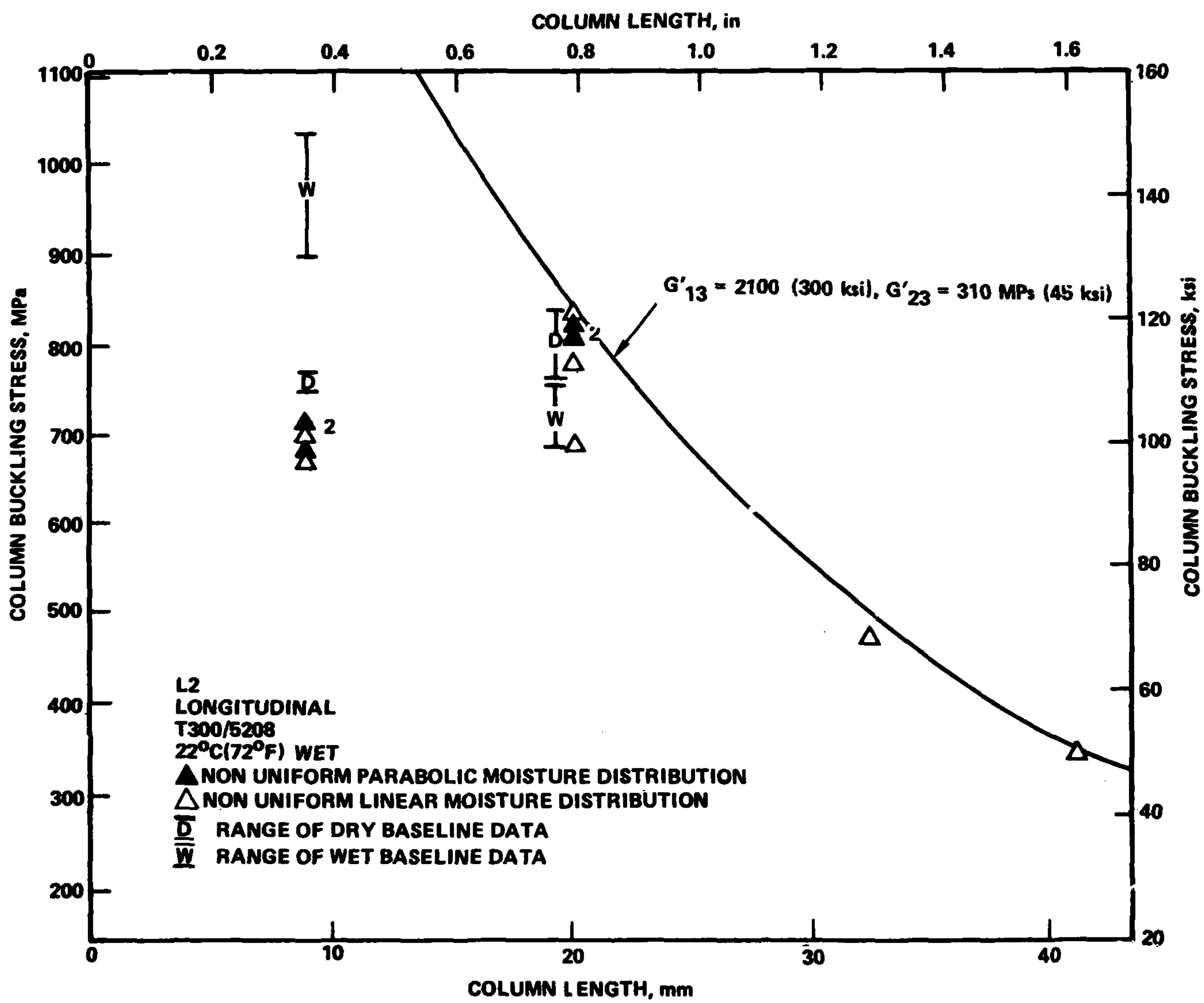


Figure 149. - Effect of non-uniform moisture distributions on column buckling behavior of T300/5208 laminate L2L at 22°C.

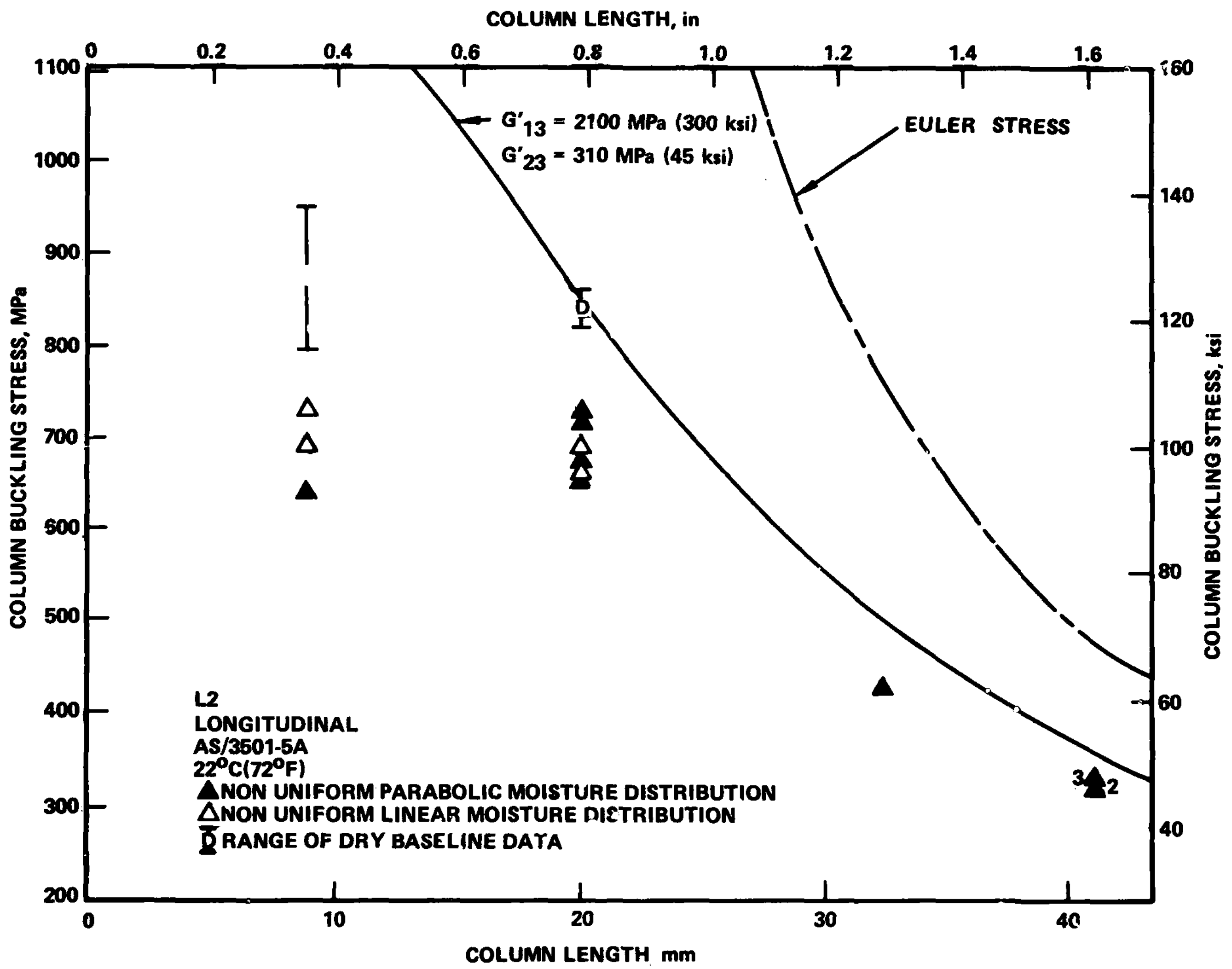


Figure 150. - Effect of non-uniform moisture distributions on column buckling behavior of AS/3501-5A laminate L2L at $22^{o}C$.

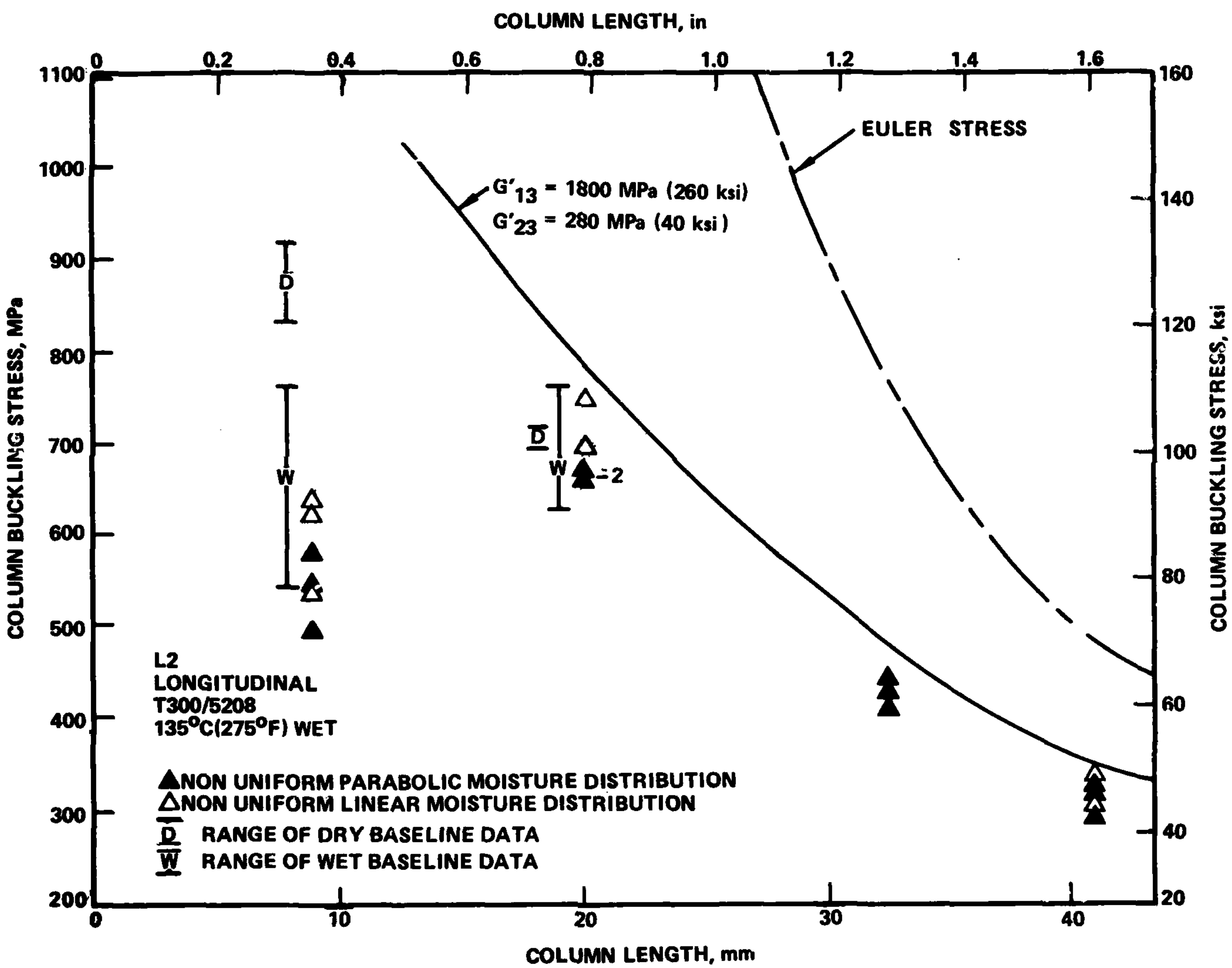


Figure 151. - Effect of non-uniform moisture distributions on column buckling behavior of T300/5208 laminate L2L at 135°C.

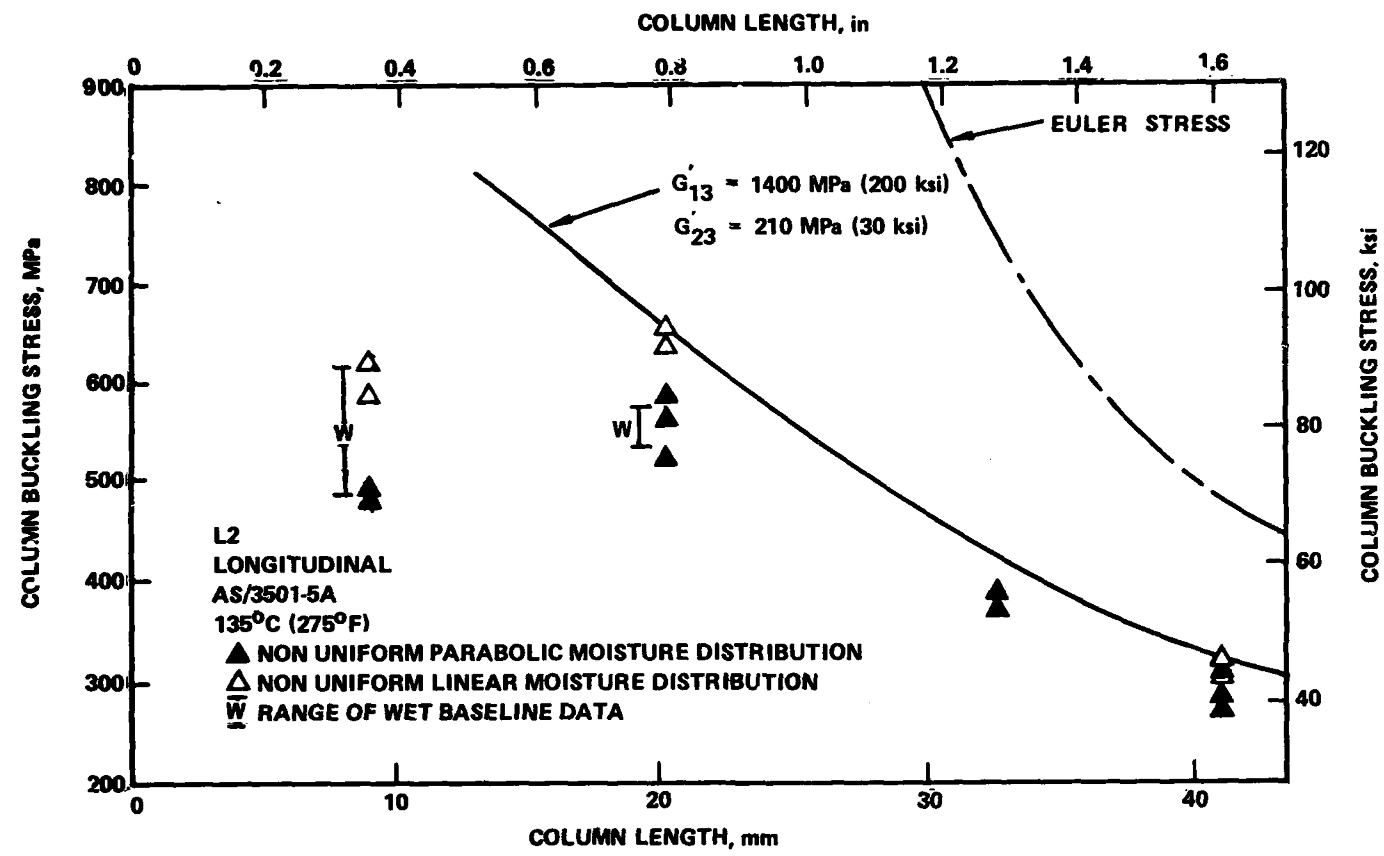


Figure 152. - Effect on non-uniform moisture distributions on column buckling behavior of AS/3501-5A laminate L2L at 135°C.

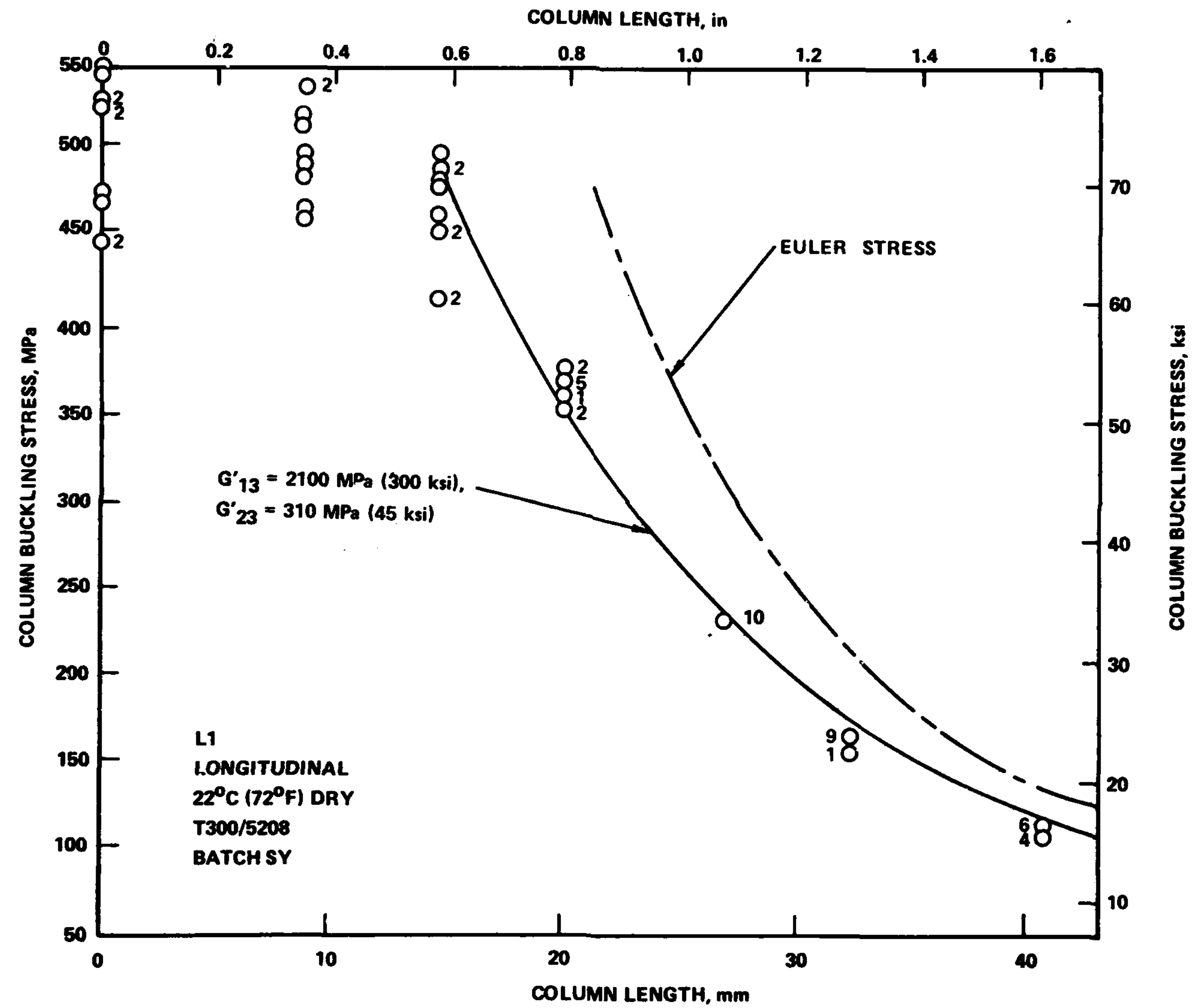


Figure 153. - Evaluation of data dispersion at room temperature for T300/5208 laminate L1L.

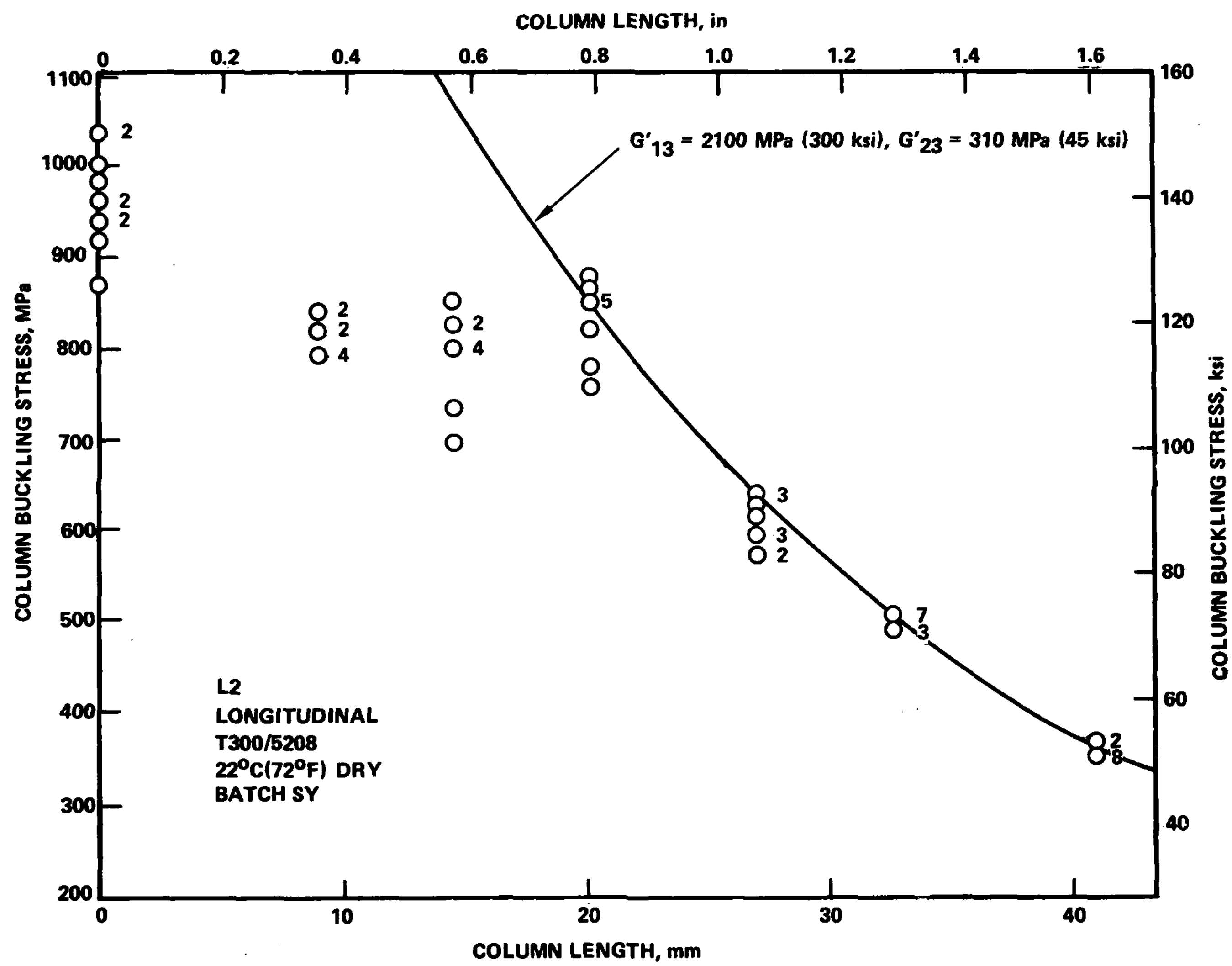


Figure 154. - Evaluation of data dispersion at room temperature for T300/5208 laminate L2L.

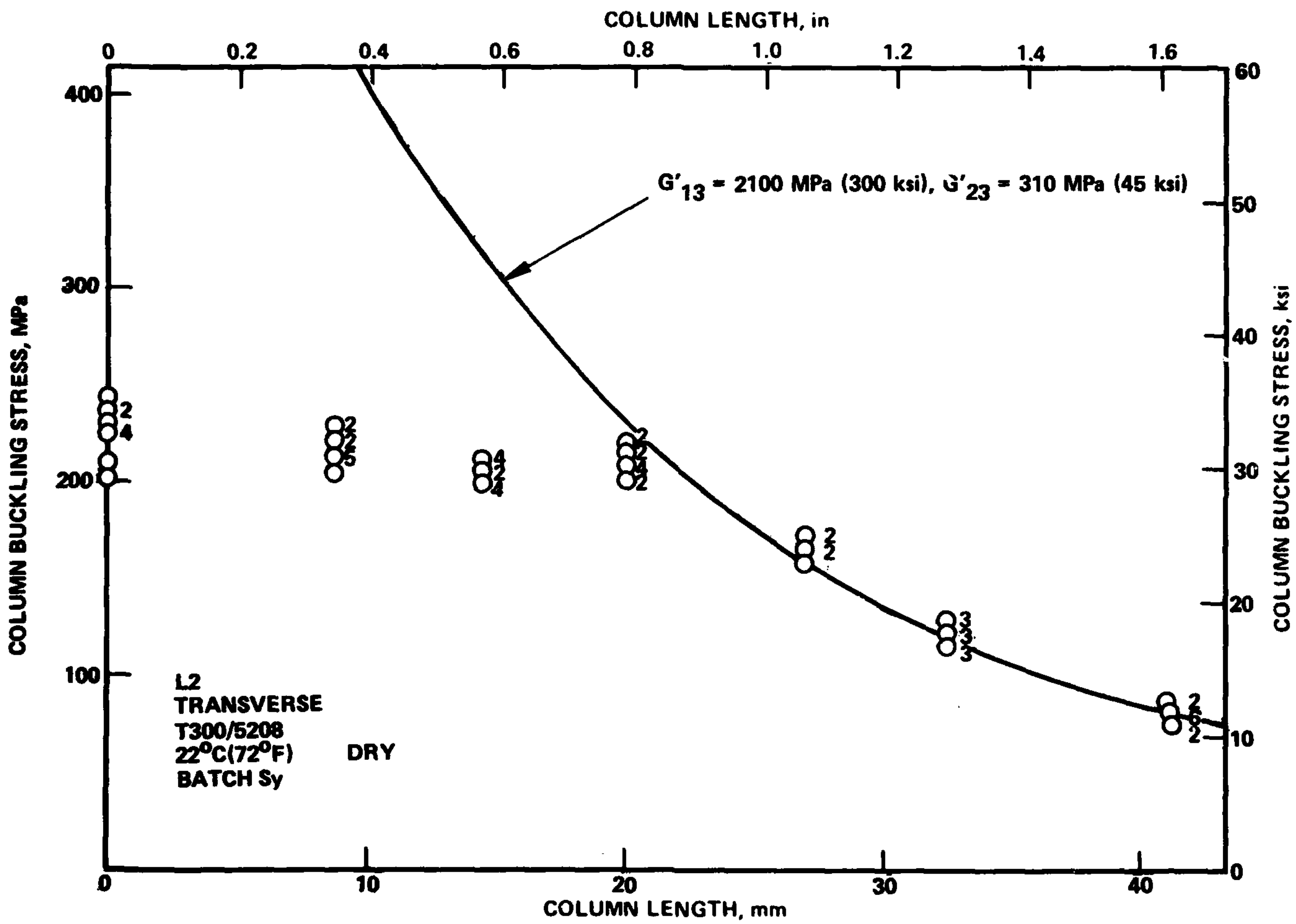


Figure 155. - Evaluation of data dispersion at room temperature for T300/5208 laminate L2T.

previously subjected to high tension load to produce microcracks are plotted in Figures 156 through 161. Comparison with scatter bands of data obtained with sound specimens and with the theoretical column curves provides no reason for attributing any change in behavior to the presence of microcracks.

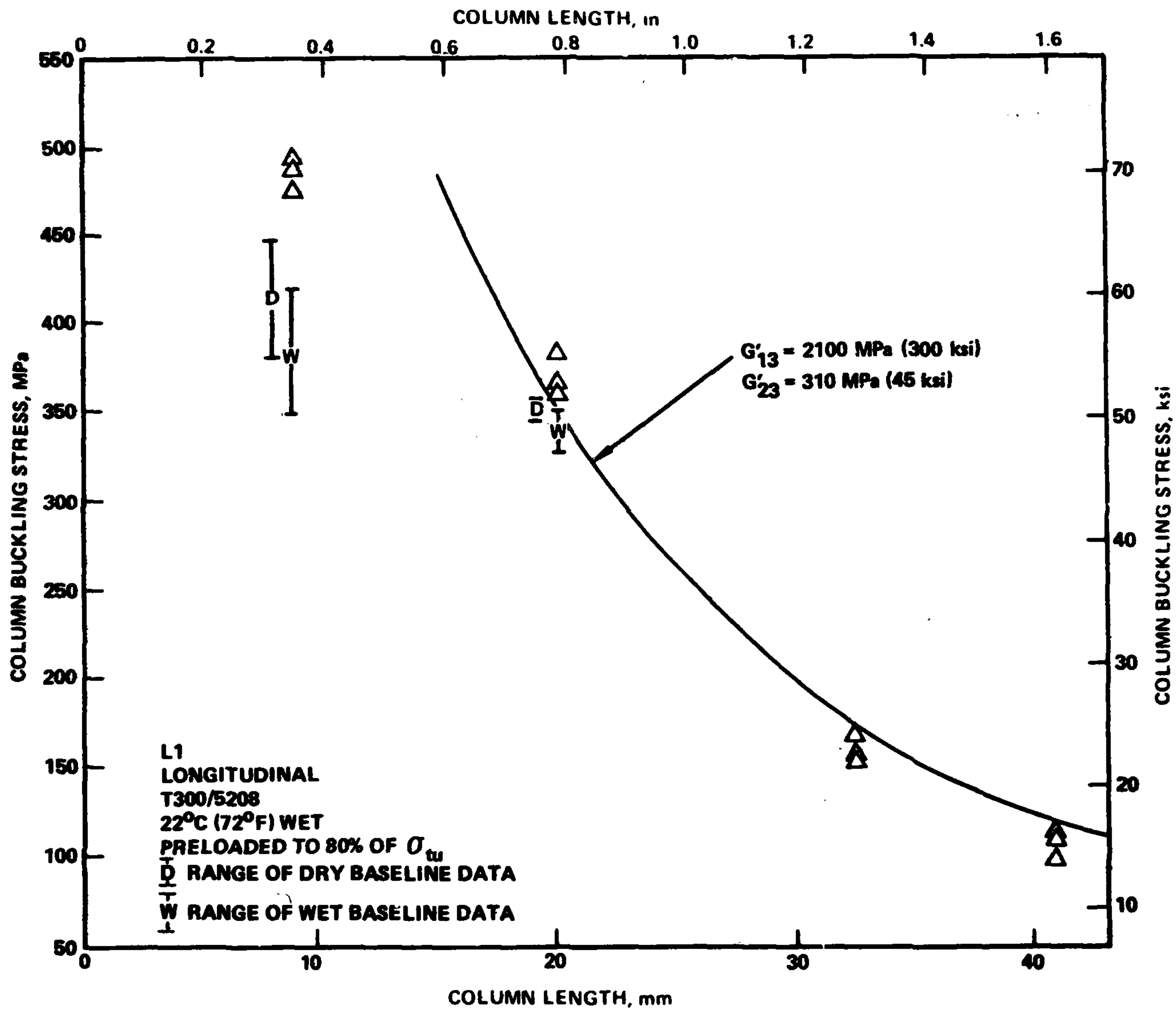


Figure 156. - Effect of microcracks on column buckling behavior of laminate L1L at 22°C.

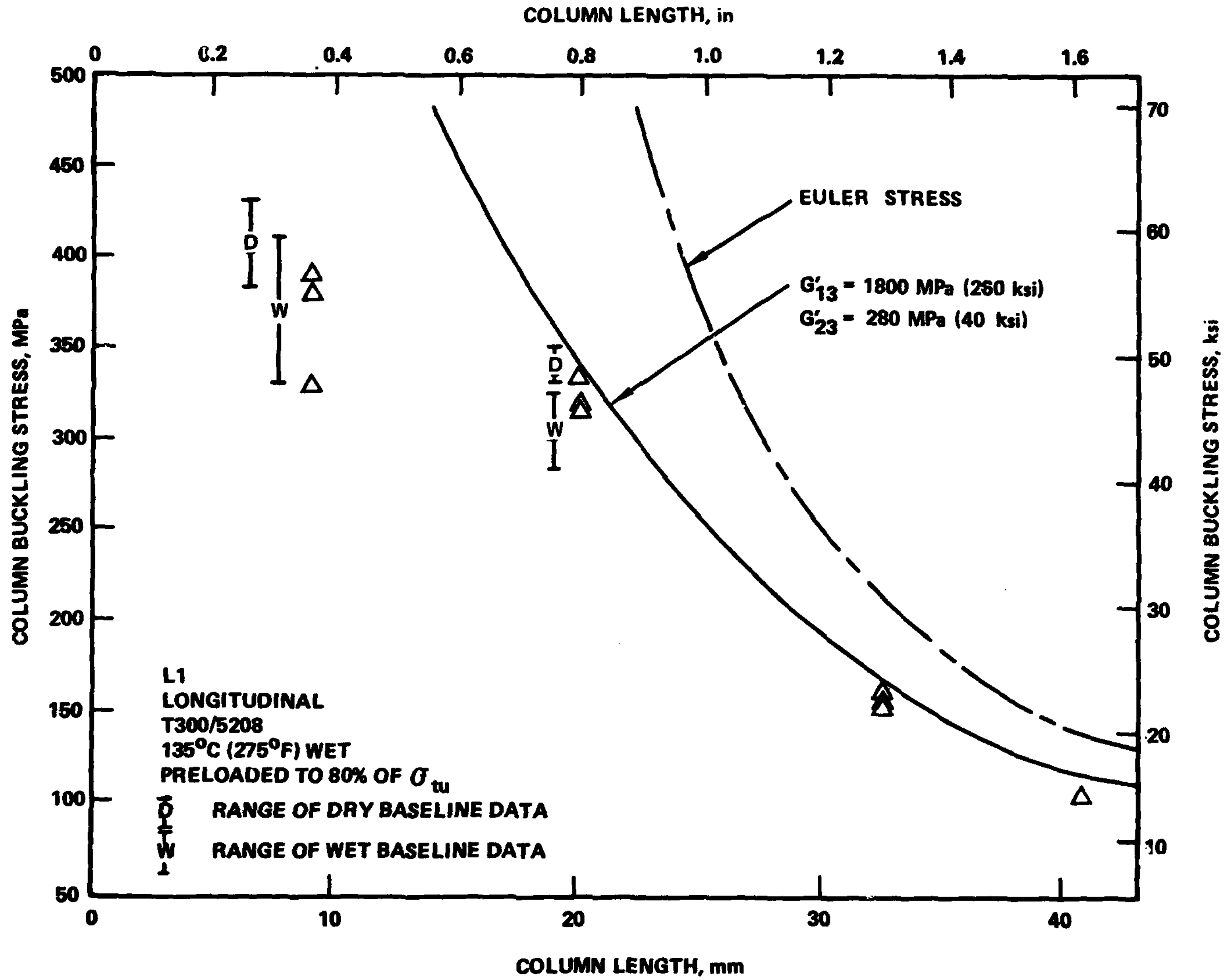


Figure 157. - Effect of microcracks on column buckling behavior of laminate L1L at 135°C.

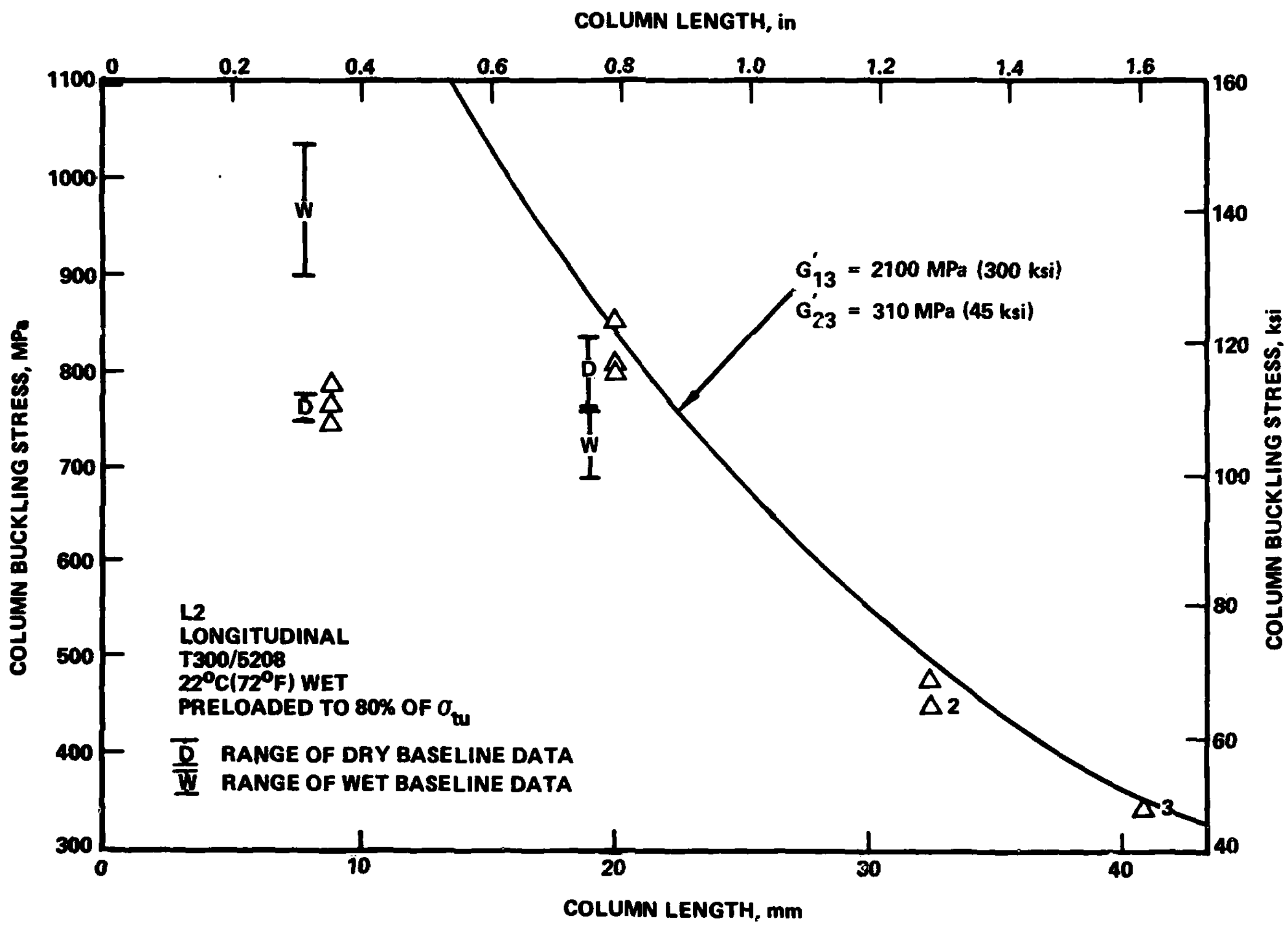


Figure 158. - Effect of microcracks on column buckling behavior of laminate L2L at 22°C.

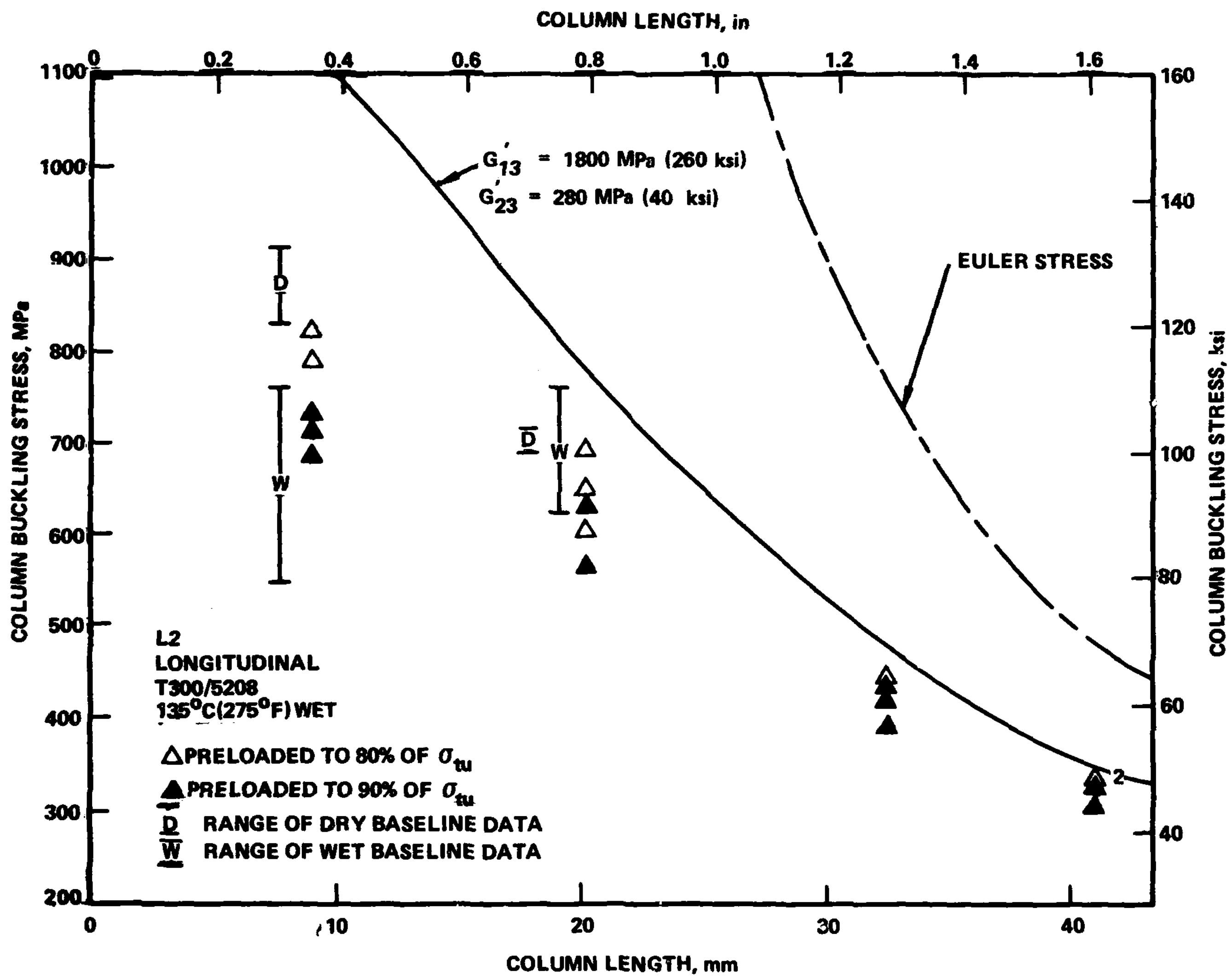


Figure 159. - Effect of microcracks on column buckling behavior of laminate L2L at 135°C.

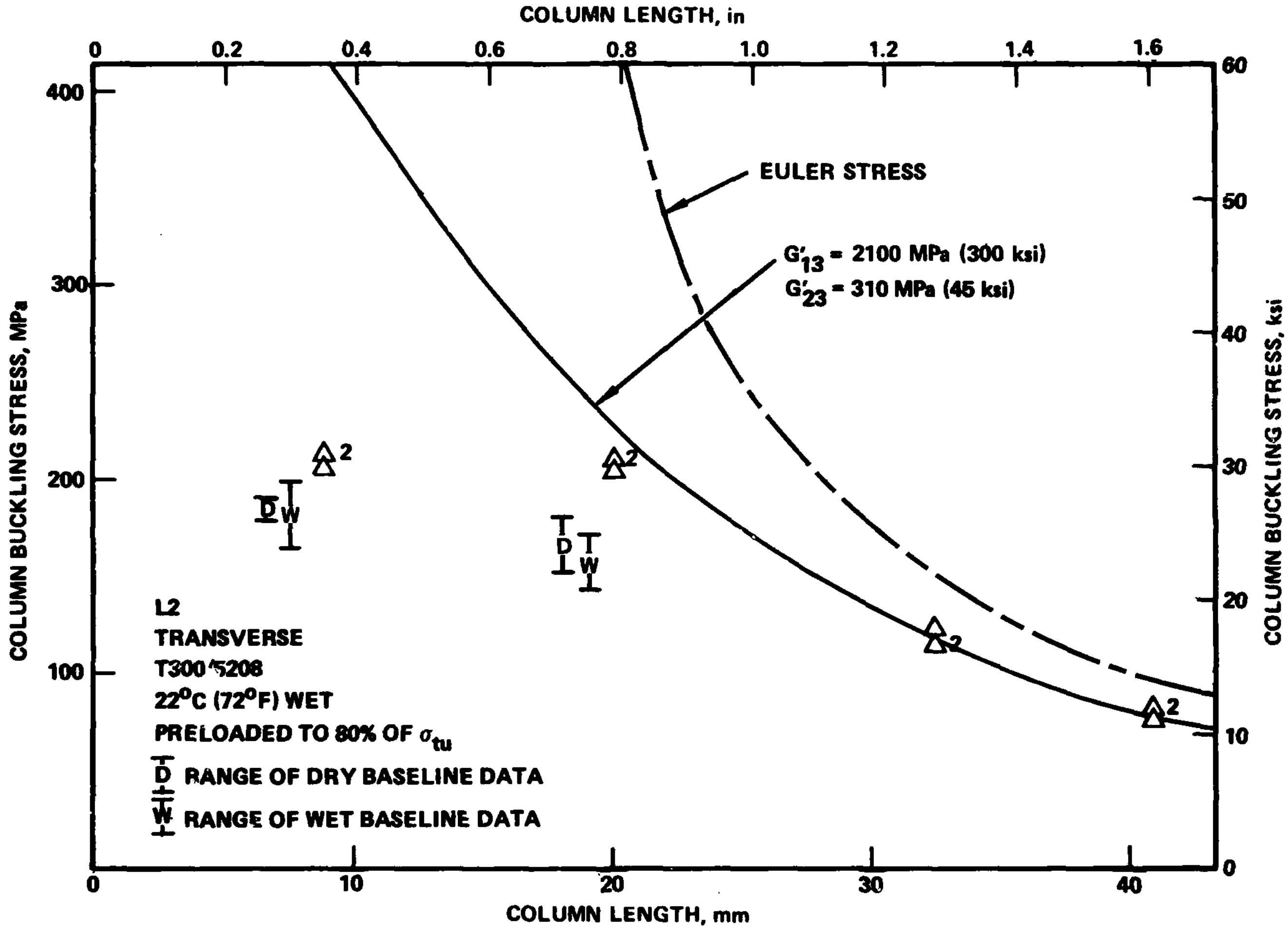


Figure 160. - Effect of microcracks on column buckling behavior of laminate L2T at 22°C.

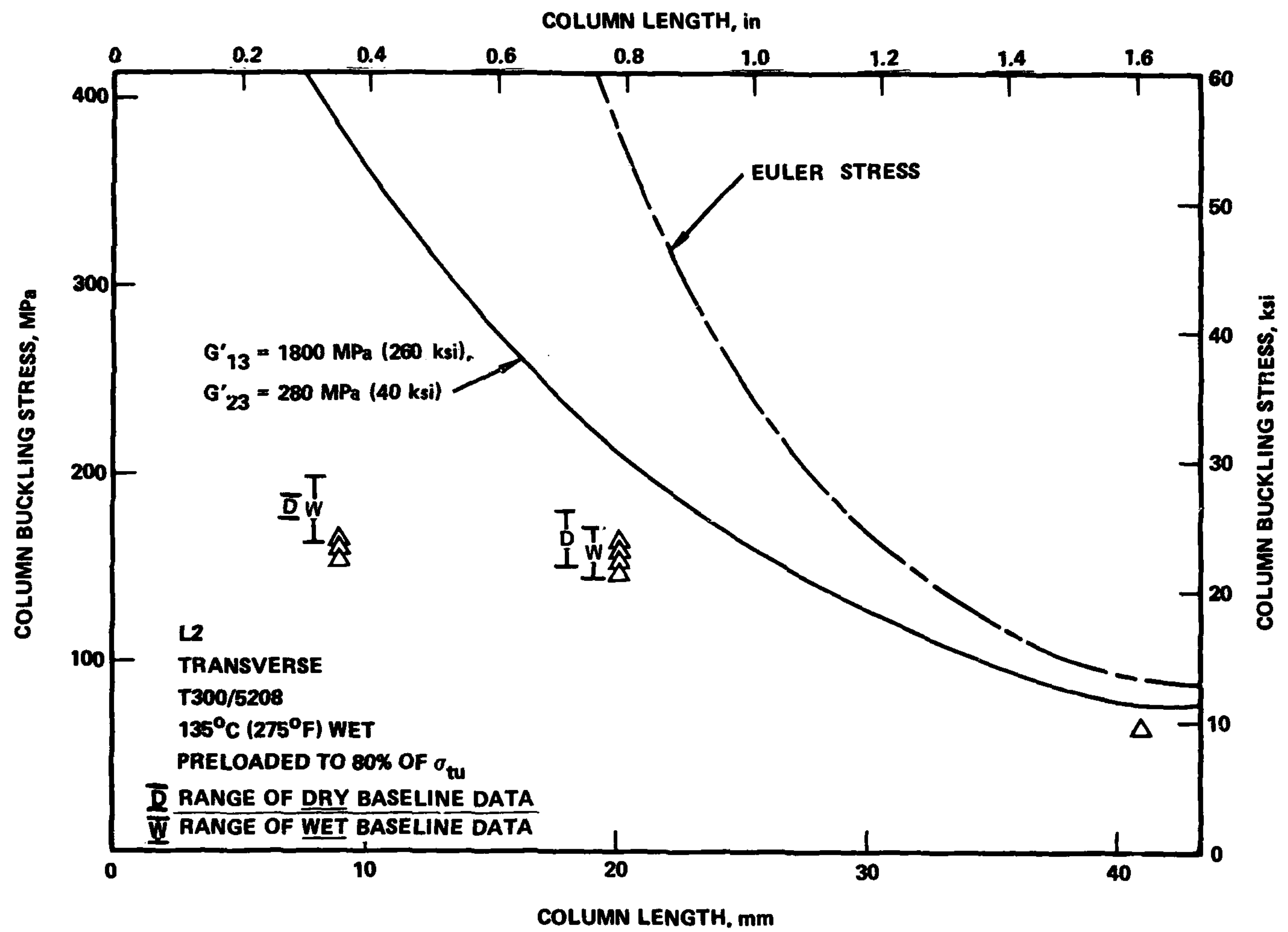


Figure 161. - Effect of microcracks on column buckling behavior of laminate L2T at 135°C.

6. CONCLUSIONS

1. Behavior of graphite-epoxy laminates under compression load may be described in three regimes: (1) a long-column range, in which stability is completely elastic; (2) a very-short-column or fully supported range, in which failure occurs by some more localized mode such as delamination or crushing, sometimes identified as a "compression ultimate"; and (3) an intermediate or short-column range, in which inelastic failures resulting in rupture occur, at stresses less than the "compression ultimate".

2. Long-column, elastic strength of the laminates tested is relatively unaffected by moisture and temperature.

3. In the intermediate and the fully-supported regimes, compression strength is reduced by moisture and temperature to an extent dependent on the material and on the layup.

4. Column and compression performance of the laminates investigated is not affected importantly or consistently by drying (as compared to stabilizing under laboratory environment), by drying prior to moisture conditioning, by non-uniform moisture distribution, or by microcracking induced by high tension loading prior to compression testing.

5. Long-column strength approaches the value predicted by the elementary Euler relation, and at very long lengths is indistinguishable from it. Shorter columns, even though still elastic, fail below the Euler value. In the intermediate length range, column instability strength falls significantly below the values predicted by elementary elastic buckling relations as well as below the limiting value established by "compression ultimate" tests.

6. Column buckling over the complete range of lengths, up to stresses at which other more localized modes of failure become dominant, can be predicted by instability theory which includes consideration of laminate shear stiffness as well as bending stiffness. These stiffnesses are determined by the material stress-strain properties of the environmentally conditioned laminate at test temperature.

7. Shear stiffness of the laminate in column action is related, not to the elastic transverse shear moduli G_{13} and G_{23} of the graphite/epoxy lamina, but to similar moduli G'_{13} and G'_{23} which are much lower than those cited in the literature which result from elastic tests under "purer" stress conditions.

8. Differences between the elastic shear moduli G_{13} and G_{23}, and the effective moduli G'_{13} and G'_{23} which fit the column test data, are believed to result primarily from the non-linear, inelastic relationship between shear stress and shear strain which is characteristic of graphite/epoxy laminates and the modification of this relation which would be expected under the combined stress conditions that exist at the critical load. A second contributing factor may be inherent eccentricity in the laminate, which augments shear deformation.

9. Similarly reduced values of the effective shear moduli may be expected to influence the instability process in all types of buckling of graphite/epoxy composite laminates. This effect is expected to be important, for example, in the prediction of crippling stresses of stiffener shapes.

APPENDIX A

QUALITY CONTROL PLAN

FOR

EFFECT OF ENVIRONMENT ON THE COMPRESSIVE

STRENGTHS OF LAMINATED EPOXY MATRIX COMPOSITES

QUALITY CONTROL PLAN

This Quality Control Plan has been prepared for U.S. Air Force Contract F33615-77-C-5140.

Manufacturing and quality assurance procedures will be applied to material and laminates, as described below, to ensure quality, uniformity and traceability of test specimens.

1. MATERIAL ACQUISITION

Narmco T300/5208 and Hercules AS/3501-5A graphite/epoxy prepreg materials conforming to Lockheed Material Specification C-22-1379/111 will be purchased for this program. Each material will be acquired in one procurement. Other materials required for the fabrication of test laminates will be purchased to the requirements given in the Lockheed Engineering Purchasing Specification (EPS) Manual, to the extent indicated in Section 3. Fiberglass for the specimen tabs will be acquired to Lockheed Material Specification LCM C-22-1032/141.

2. MATERIAL ACCEPTANCE

The prepreg material supplier will be required to provide a certificate of conformance, including test data, resin/catalyst age, and date of mixing with each delivery. Lockheed Quality Assurance Laboratories will then conduct acceptance tests on the delivered material in confirmation of supplier data. These tests will include:

- Uncured Properties
  - o Fiber orientation
  - o Resin content
  - o Volatiles content

- o Resin flow
- o Gel time
- o Infrared Analysis
- o Areal Weight

- Mechanical and Physical Properties of Cured Material

  - o Void Content
  - o Specific Gravity
  - o Cured Resin Content or Fiber Volume
  - o Interlaminar Shear
  - o Longitudinal Tensile Strength and Modulus
  - o Longitudinal Flexural Strength and Modulus
  - o Cured Ply Thickness

The test methods and acceptance limits shall be as specified in the applicable material specifications, C-22-1379/111 and C-22-1379A. Materials not conforming to the requirements of the Specifications will be rejected.

Material specifications further stipulate preparation-for-delivery provisions covering date of shipment, allowable time and temperature in transit, and vapor-tight packaging required for supplier and transporter conformance. Materials requiring refrigerated storage will be placed in Quality Assurance-approved refrigerators immediately upon receipt. Pending acceptance by the Quality Assurance laboratory, all materials will be kept segregated and withheld from use. After acceptance, each container, roll, or spool of material will be stamped or otherwise approved by Quality Assurance and controlling labels will be attached.

3. MATERIAL PROCESSING

This section establishes the requirements and procedures for the lamination of graphite/epoxy test panels, fabrication of glass/epoxy tab stock and bonding of tabs to coupons.

3.1 Applicable Documents and Materials

The following documents form a part of this procedure to the extent specified herein.

3.1.1 Lockheed Materials Specifications

Lockheed Material Specification, C-22-1379A Graphite Fiber Non-Woven Tape and Sheet, Resin Impregnated, General Specification for.

Lockheed Material Specification C-22-1379/111 Graphite Fiber Non-Woven Tape and Sheet, 350 ksi Strength, 33 MSI Modulus, 350°F Curing, Epoxy Preimpregnated.

Lockheed Material Specification LCM C-22-1032/141 Glass Fabric/Epoxy Preimpregnated, 350°F Cure.

3.1.2 Commercial Materials

3.1.2.1 The following commercial materials, covered by the Lockheed Engineering Purchasing Specification (EPS) Manual, form a part of this procedure to the extent specified herein.

Material	EPS Item No.
Vacuum Bag Nylon Film	22.9001
Parting Agent Film	22.9004
Porous Release Cloth	22.9030
Peel Ply	25.5910
Stick Contact Adhesive	30.0650

3.1.2.2 The following commercial materials not covered by the Engineering Purchasing Specification Manual are required for use in this procedure.

American Cyanamid Co.	FM-400 Epoxy Adhesive Film, 0.07 lbs/ft^2, 350°F Cure
Air Tech International Inc.	Flashbreaker 5 Pressure Sensitive Tape

3.2 Material Control

All materials shall conform to the applicable specifications.

3.2.1 Storage and control requirements shall be as specified in Table A-1. Refrigerated material shall be stored in sealed, moisture vapor proof containers.

3.2.2 Refrigerated materials shall be thawed until moisture no longer condenses on the moisture-proof containers.

3.2.3 All perishable materials shall have had validation tests performed within 30 days of use, if initial storage time limit has been exceeded. Validation tests are the same as those shown in Table A-1.

3.2.4 A manufacturer's identified defects (MID's) record is furnished with each roll of Gr/Ep by the material supplier. This record shall be furnished to the Composites Laboratory with each roll of Gr/Ep.

3.2.5 Stored perishable material in which visible water is observed in the bag shall be rejected.

TABLE A-1

MATERIAL CONTROL

Material	Max. Storage Temp.	Maximum Storage Time Before Retesting, Days		Minimum Required Tests	Max. Allowed Out Time During Proc. @75°F & 55% R.H.
		Initial	Subsequent		
Gr/ep Prepreg	0°F	180	60	△1 △2	14 days
Adhesive Film	0°F	180	90	Climbing Drum Peel @ -65°F	10 days

△1 Flow and gel time, room temp. flexural and short beam shear, specific gravity and resin content.

△2 See applicable Material Specifications for test methods and requirements.

3.3 Environmental Control

3.3.1 All work shall be done in controlled areas to avoid degradation of the materials and laminates. Temperature shall be between 65-80°F and relative humidity shall not exceed 55%.

3.3.2 All incoming air into controlled areas shall be filtered by at least a 1½-inch thick throw-away type of permanent washable type filter or by an equivalent method. Inspect and clean filters monthly.

3.4 Tooling

3.4.1 All tools shall be designed and coordinated to produce parts that meet all requirements of this specification and the Engineering drawing. Tools shall have the minimum mass necessary for dimensional and thermal control.

3.4.2 All tool plates used for curing laminates shall be aluminum. Thickness of the caul plate shall be 0.500 in. with a tolerance of ±0.003 in., flat and parallel. Caul plates used on top surface of laminate under the vacuum bag shall be aluminum sheet 0.064 in. standard thickness.

3.4.3 Tooling parting agents and cleaners shall not contaminate the laminates or interfere with subsequent bonding, finishing and inspection.

3.5 Material Preparation

3.5.1 Templates or patterns shall be placed on the prepreg in such a way as to ensure that the fiber direction is in accordance with Engineering drawing requirements and does not include any MID's flagged by the supplier (see 3.2.4).

3.5.2 Panels will be laid-up such that the edges of tape are parallel or perpendicular to the required fiber direction within 1°.

3.5.3 All areas from which material will be cut shall be checked prior to cutting for the defects defined in C-22-1379, Quality and Condition Requirements, which may not have been flagged by the manufacturer. Material containing unacceptable defects will not be used. Patch plies are not permitted.

3.5.4 Plies shall be cut with sufficient care so as not to disorient fibers. Cutting tools shall be cleaned prior to use on prepregs.

3.5.5 No ply end butt splices are permitted in the laminate assembly.

3.6 Tool Preparation

3.6.1 The tool molding surfaces shall be solvent wiped and all resin removed prior to layup.

3.7 Panel Lay-up

3.7.1 The preimpregnated graphite tape shall be placed on the tool in the sequence and orientation specified on the Engineering drawing or Engineering Test Request. As each ply is placed on the assembly, it shall be checked for the defects defined in C-22-1379 prior to applying the ply firmly in place. A check-off system shall be used to assure proper orientation and stacking sequence of each ply.

3.7.2 The surface of each ply shall be wiped with a teflon, polyethylene or equivalent device to give maximum adhesion to the previous ply. Wiping shall be done only in the direction of the fibers to prevent fiber separation and distortion. Wiping the surface should be done only when the orientation of the tape edge has been verified to be within ±1° of the drawing requirement. Excessive pressure shall not be applied during wiping and wiping shall be kept to a minimum.

3.7.3 Parallel plies shall be laid up so that edge splices are staggered a minimum of 1.0-inch in adjacent plies and do not coincide within a 5 ply thickness.

3.7.4 Edge splices shall be butted flush, ±0.03 inch.

3.7.5 Entrapped air in blisters that cannot be wiped out without distorting fibers shall be removed by puncturing the blister with a needle or pointed sharp blade as often as needed and wiping in the direction of the fibers toward the puncture. Care shall be taken not to damage the under ply fibers.

3.7.6 Where permanent edge steps or dams are not incorporated in the tool for edge thickness control, an edge dam shall be built around the perimeter of the laminate. The dam shall not be more than 0.06-inch from the laminate edge and shall be of sufficient height to enclose the laminate. The bleeder may not extend over the dam surface. Joints in the dam shall be kept to a minimum. Dam joint gaps shall not exceed 0.03-inch.

3.7.7 A dry peel ply of fabric (EPS 25.5910) or equivalent shall be placed on both sides of the layup and wiped smooth.

3.7.8 A bleeding and bagging system of the following construction shall be used.

(a) Cure plate

(b) Separator film - perforated parting agent film or porous release cloth.

(c) Mochburg CW1850 bleeder paper (1 ply for 4 plies of prepreg.)

(d) One ply of porous Teflon-coated glass cloth (DuPont Armalon)

(e) Nylon peel ply

(f) Graphite/epoxy laminate

(g) Nylon peel ply

(h) One ply Armalon

(i) Mochburg CW1850 bleeder paper (4:1 ratio)

(j) Release film

(k) Caul plate (aluminum)

(l) One ply Mochburg CW1850

(m) Release film

(n) Glass breather

(o) Nylon film vacuum bag placed over the laminate and sealed to the tool face.

3.7.9 Curing

Pressure and cure cycle should be within the limits given in Tables A-2 and A-3.

TABLE A-2

CURE CYCLE T300/5208

1.	Apply full vacuum
2.	Heat to 275° ±5°F @ 2-3°F/min.
*3.	Dwell @ 275° ±5°F for 30 ±1 minutes
4.	Apply 100 ±5 psi vent vacuum to air @ 20 psi.
5.	Heat to 355 ±5°F @ 2-3°F/min.
6.	Cure for 120 ±10 min. @ 355 ±5° F.
7.	Cool to 140 ±5°F under pressure @ less than 4°F/min.
8.	Cool to room temperature.

* NOTE: Dwell time started when temperature reaches 265°F.

TABLE A-3

CURE CYCLE FOR AS/3501-5A

1.	Heat to 265°F under full vacuum at 2° to 3° per minute.
2.	Dwell at 265°F under vacuum only for 15 minutes.
3.	Apply 10 psi and dwell 15 minutes.
4.	Apply 85 psi, maintaining vacuum.
5.	Heat to 350°F at 2° to 3° per minute.
6.	Cure 4 hours at 350°F
7.	Cool to 180°F under pressure @ less than 4°F/min.
8.	Cool to room temperature

3.8 Laminate Control Specimens

Each panel will be laid up to contain an excess strip at least one inch wide and running either the length or width of the panel. The strip must be located at least one inch from the panel edges.

3.8.1 Laminate control coupons will be cut from this strip for the determination of resin content, specific gravity and average ply thickness. Test requirements are given in Table A-4.

3.8.1.1 Void volume fraction will also be measured on laminate control coupons from selected panels using standard metallographic techniques. This method will be used to confirm results calculated from the acid digestion and density measurement values.

3.9 Workmanship

All laminated details and bonded assemblies shall be of highest quality. Conditions in excess of the following shall be cause for rejection.

TABLE A-4

TEST REQUIREMENTS

Test	Requirements	
	T300/5208	AS/3501-5A
Fiber Volume	65 ±2%	62 ± 2%
Specific Gravity	1.56 - 1.60	1.55 - 1.62
Thickness/Ply	.0046 - .0053 inch (Report for information only)	

3.9.1 There shall be no evidence of surface cracking, uncoated fibers, excess resin, pits, tackiness or other indications of defective resin characteristics or distribution.

3.9.2 No visual delaminations are allowed.

3.9.3 The laminate shall be essentially void free. Calculated voids shall not exceed 1.0 volume percent without special engineering review.

3.9.4 Wrinkles

3.9.4.1 No wrinkles containing graphite fibers are permitted. Resin wrinkles caused by peel ply gathering or by the bleeder system shall not be cause for rejection if the resin ridge can be removed without damaging the graphite fibers using 320 grit or finer sandpaper.

3.9.5 The presence of foreign material, e.g., separator film, masking tape, etc., in the part is not acceptable.

3.9.6 There shall be no sharp or frayed edges, nor edge delaminations resulting from trimming and routing operations.

3.10 Cleanup

Chemical strippers shall not be used in any way to remove excess resin or adhesive. If removal is necessary, it shall be done with an abrasive, and shall not damage any surface graphite fibers.

3.11 Records

The following records are required for permanent retention and traceability.

1. Temperature-pressure-vent-time profile record for each cure cycle.
2. Thermocouple locations.
3. Material batch and roll number, acceptance laboratory report number and cumulative out-time up to the time of vacuum application.
4. A completed autoclave record sheet as shown in Figure A-1.

3.12 Machining of Test Specimens

Specimens are to be machined to the dimensions shown in Figure A-2. Specimen cuts will be made parallel to the panel edge to ±1 degree. Cutting rates will be chosen to minimize edge damage.

3.13 Fabrication and Bonding of Glass Fabric/Epoxy Grip Tabs

3.13.1 Grip tab sheet material shall be fabricated by laminating the required number of plies of Style 181, 1581, or 7581 glass fabric/epoxy prepreg. For most standard coupons, the laminate consists of 6 plies or 3 plies in thickness depending on the type of coupon. Thicknesses and other dimensions shall be in accordance with Figure A-2. Tab dimensions shall be as specified on specimen drawing.

3.13.2 The material used for grip tab stock shall be glass/epoxy prepreg. Conforming to Lockheed Material Spec. LCM C-22-1032/141. This material shall be cured at 350°F for one hour under a pressure of 35 psi plus vacuum. A caul sheet shall be used under a vacuum bag for pressure application.

Run#________

ETR/Dwg.#________________Panel I.D.________________Matl. Code________________

Q.A. Lab. Report #______________Made for________________Date________________

I. Description of Materials

Designation__________________Batch#________Roll#__________ Date Mfd.__________

No. of Plies ________ Orientation________________________________

II. Cure Press. ________ psi	CURE CYCLE (NARMCO)
Cure Temp ________ °F	1. Apply full vacuum
Cure Time ________ min.	2. Heat to 275° ±5°F @ 2-3°F/min.
Vac. Bag ________ inch-Hg	*3. Dwell @ 275° ±5°F for 30 ±1 min.
	4. Apply 100 ±5 psi & vent vac to air @ 20 psi.
III. Autoclave Pressurization	5. Heat to 355 ±5°F @ 2-3°F/min.
Time @ start __________	6. Cure 120 ±10 min. @ 355 ±5°F
Time @ press.__________	7. Cool to 140 ±5°F under press. @<4°F/min.
Delta Time min.__________	8. Cool to R.T.
	*NOTE: dwell time starts when temp reaches 265°F.
IV. Temp__________°	

V. Temp__________°F @ lay-up V. %R.H.______________@ lay-up

VI. TIME RECORD

	1		2		3		4		5	
	Temp	Time	Temp	Time	Temp	Time	Temp	Time	Temp	Time
Start heat										
At temp.										
Time to temp min.									OFF	
Time @ temp min.										
Heat-up rate°F/min.										
Cool-down rate°F/min.										

VI. Panels

I.D.	Size(in.) ___x___	No. Plies	Meas. Thick

VIII. Bleeding & Bagging

__________ nylon bag
__________ 181 glass breather
__________ vac pac
__________ Mochburg (1 ply)
__________ caul plate
__________ vac pac
__________ Mochburg (4:1 ratio)
__________ armalon
__________ nylon peel ply
__________ LAMINATE
__________ nylon peel ply
__________ armalon
__________ Mochburg
__________ vac pac
__________ cure plate

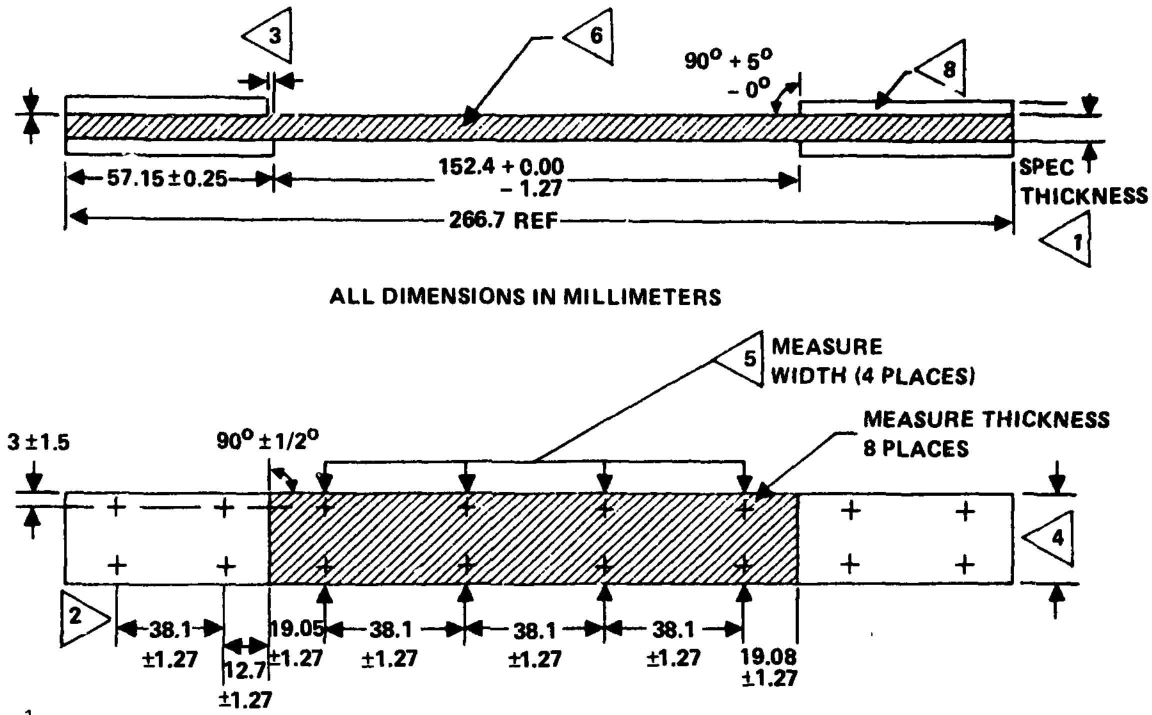
IX. Comments

Signature of Inspecting Engineer

____

NOTE: Laminate completely dammed perforated vac pac taped to dam.

Figure A-1. - Sample autoclave record.



9. SPECIMENS TO BE FLAT OVER THE ENTIRE 267-mm (10.5-in.) LENGTH WITHIN 0.25-mm (0.01-in.)

8. TAB EDGES TO BE PARALLEL TO SIDES OF SPECIMEN WITHIN 0.025-mm (0.001-in.) OVERHANG NOT TO EXCEED 3.8-mm (0.15 in.).

7. THE TAB AND SPECIMEN BONDING SURFACES TO BE THOROUGHLY SOLVENT CLEANED USING METHYL-ETHYL-KETONE PRIOR TO BONDING. A 177°C (350°F) CURING ADHESIVE TO BE USED AND MUST COVER ENTIRE SURFACE UNIFORMLY.

6. SPECIMENS TO BE CUT DRY. MACHINED SURFACES TO BE RMS 50 OR BETTER. NO EDGE DAMAGE OR FIBER SEPARATION SHOULD BE VISIBLE UNDER 10X MAGNIFICATION.

5. MEASURE SPECIMEN WIDTH 4 PLACES. WIDTH MUST NOT VARY BY MORE THAN 0.102-mm (0.004-in.)

4. SPECIMEN WIDTH TO BE $25.4^{+0.00}_{-0.50}$ mm ($1.00^{+0.00}_{-0.02}$ in.).

3. MISMATCH OF TABS FROM SIDE TO SIDE NOT TO EXCEED 0.25-mm (0.01-in.)

2. TABS TO BE CUT FROM AN 8 PLY LAMINATE FABRICATED FROM PREPREG OF 1581 GLASS FABRIC IN A 177°C (350°F) CURING EPOXY. TAB PLUS ADHESIVE THICKNESS MUST NOT VARY SIDE TO SIDE OR END TO END BY MORE THAN 0.25-mm (0.01 in.) AS MEASURED 8 PLACES.

1. SPECIMEN THICKNESS TO BE WITHIN ±0.08-mm (±0.003-in.) OF THE AVERAGE OF 8 THICKNESS MEASUREMENTS.

Figure A-2. - Composite Compression Test Specimen

3.13.3 The adhesive used for bonding tabs to coupons shall be American Cyanamid Co. FM-400, 0.07 lbs/ft^2. Aluminum caul plates ¼ to ½-inch thick shall be used to apply bonding pressure on tabs. Cure adhesive at 350°F ±5°F for 60 to 70 minutes using 15 ±1 psi positive pressure on bondline (no vacuum). Cool to 170°F under pressure.

4. QUALITY ASSURANCE PROVISIONS

To produce test panels of consistent quality, strict adherence to all the minimum Engineering requirements of Section 3 is vital. The requirements of Section 4 are intended to outline the minimum amount of inspection and surveillance before, during, and after processing testing to confirm that adherence has been achieved.

4.1 Material

Verification shall be made that only adhesives and prepreg materials are used that are approved to the material specifications specified.

4.1.1 Adhesive or prepreg material which is stored below room temperature shall be wrapped in a closed impermeable bag at all times. Evidence of material cracking or moisture condensation on the material is cause for rejection. Exposure to ambient temperature shall be minimized.

4.1.1.1 Adhesive or prepreg material which is withdrawn from storage and left out 30 minutes or more before returning to the box, shall have the out-time marked on an appropriate tag attached to the roll. Material for which accumulated out-time at ambient temperature exceeds the allowable out-time given in Table A-1, shall not be used.

4.1.2 All adhesive and prepreg materials shall be controlled as to batch, lot, and roll numbers for traceability.

4.1.2.1 Material which has exceeded the allowable storage shall not be used unless tested within one week prior to use.

4.1.2.2 All refrigerated materials shall be checked for compliance to 3.2.2 prior to use.

4.2 Panels and coupons shall be clearly marked before and after application of tabs to indicate the bag side of the graphite/epoxy laminate as originally cured. Panels shall be identified with a number including material code and autoclave run number. Coupons shall be identified with panel number from which cut and a dash number indicating location.

Example: ILY 556-1A

Coupons shall be numbered consecutively as they are cut from panels to indicate relative location in the panel.

4.3 Equipment and Facilities Control

Equipment and facilities used for materials storage, processing, and inspection shall be controlled in accordance with LCP79-1053.

4.4 An effective quality control system shall be provided to ensure compliance with the requirements of this procedure as specified in the following sections.

4.4.1 Material Acceptance testing will be performed by Lockheed Quality Assurance Laboratories.

4.4.2 Panel and tab fabricating and tab bonding will be accomplished by personnel of the Composites Laboratory at Rye Canyon Research Laboratories. Layup and cure of panels will be witnessed and inspected by Engineering.

4.4.3 Specimens will be machined to required dimensional tolerances by machinists at the Rye Canyon Shops or other Engineering approved shop. Dimensional inspection of specimens will be the responsibility of Lockheed Quality Assurance.

4.4.4 The principal investigator will have final acceptance/rejection authority for material, panels and specimens.

4.4.5 An engineering approved autoclave record will be maintained for each panel.

4.5 Non-Destructive Inspection

4.5.1 All test panels shall be non-destructively inspected for internal defects by ultrasonic "C" Scan procedure. Standard reference 2 mil thick teflon pads of 1/8-inch to 1/4-inch diameter will be placed at one corner of each panel. A permanent record of the C-Scan results shall be retained with the records required in 3.11.

4.5.1.1 Specimens will not be cut from areas in the panels which show indications comparable to the standards.

APPENDIX B

PANEL LAYOUTS

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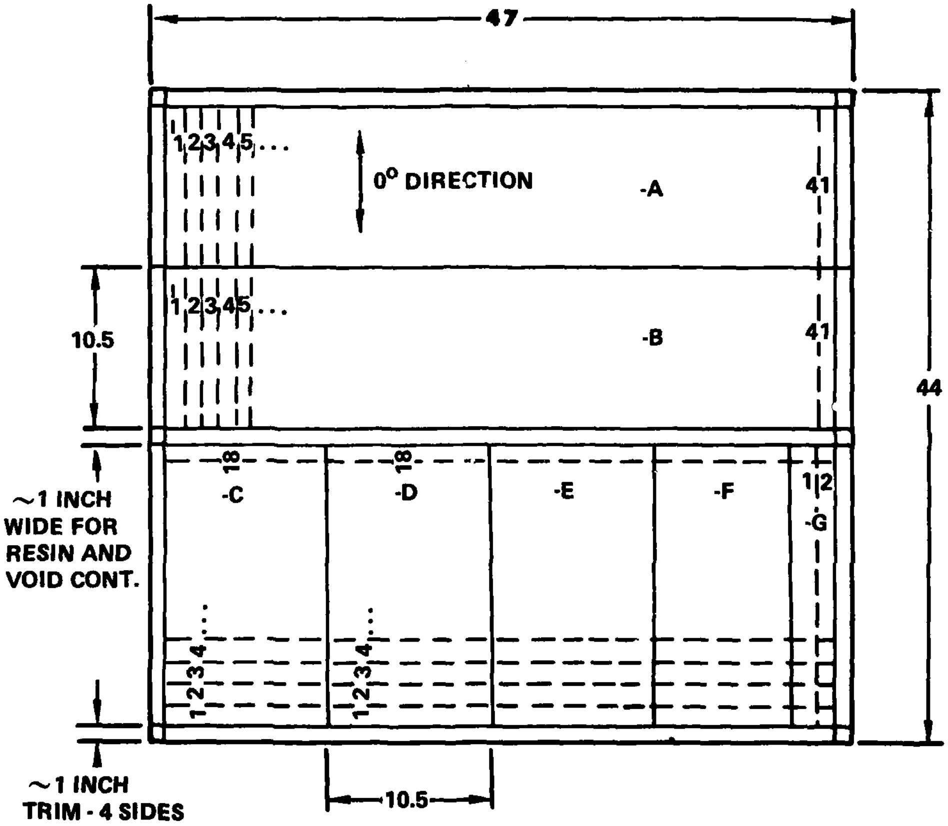


Figure B-1. - T300/5208 panel layout for laminate L1 (quasi-isotropic) $(0/45/90/-45_2/90/45/0)_S$ - 16 plies.

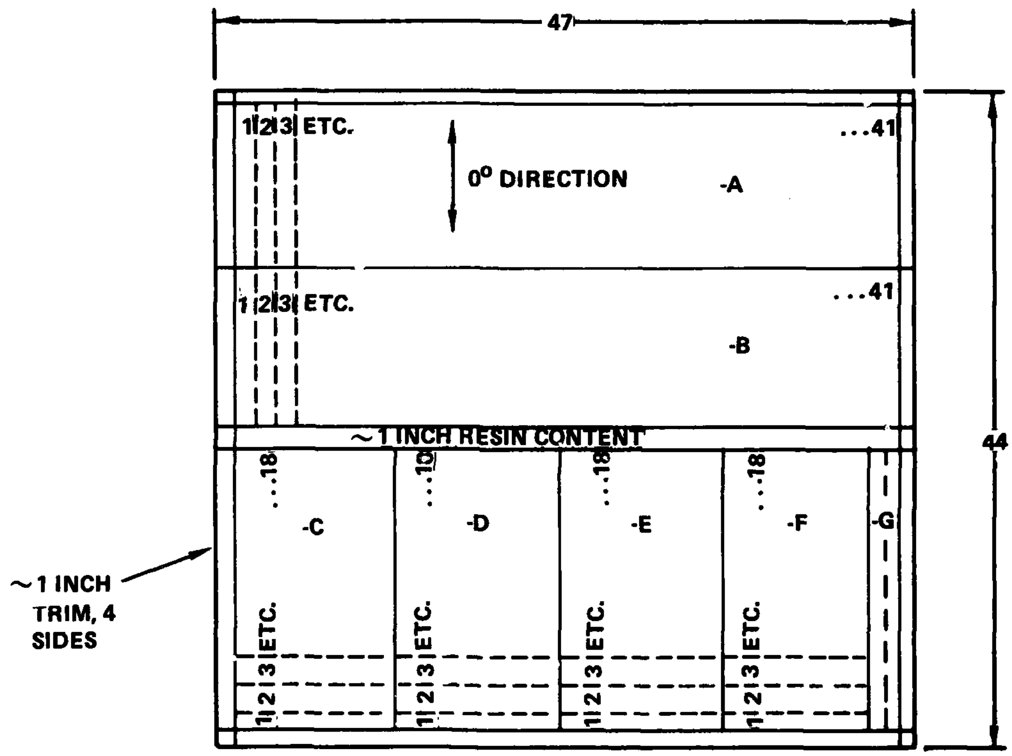


Figure B-2. - T300/5208 panel layout for laminate L2 67%-0°, 33% - $\pm 45^{\circ}$ $(0/45/0_2/-45/0_2/45/0_2/-45/0)_S$ - 24 plies.

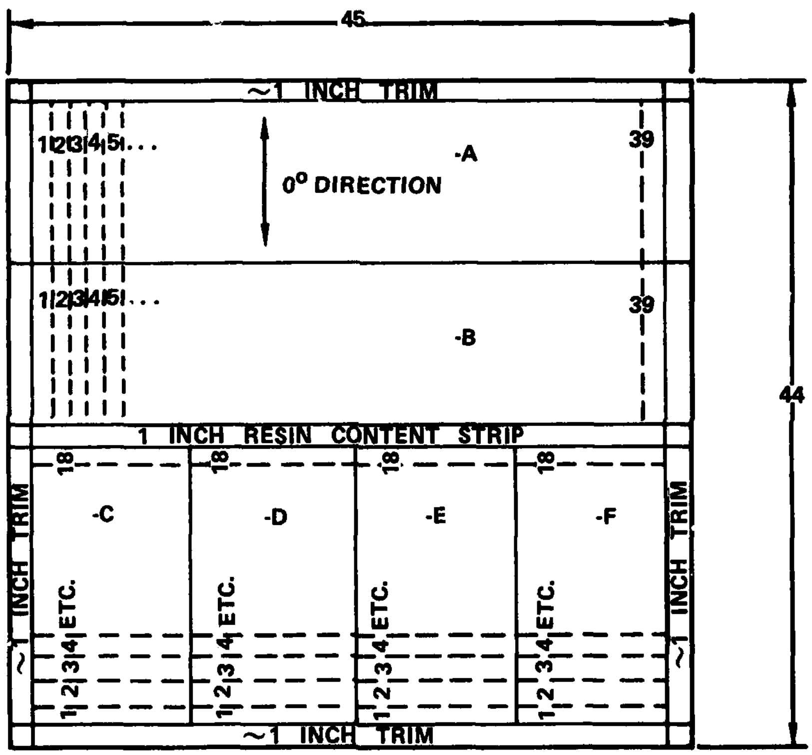


Figure B-3. - T300/5208 panel layout for laminate U1 100% - 0° unidirectional $(0)_{16}$ - 16 plies.

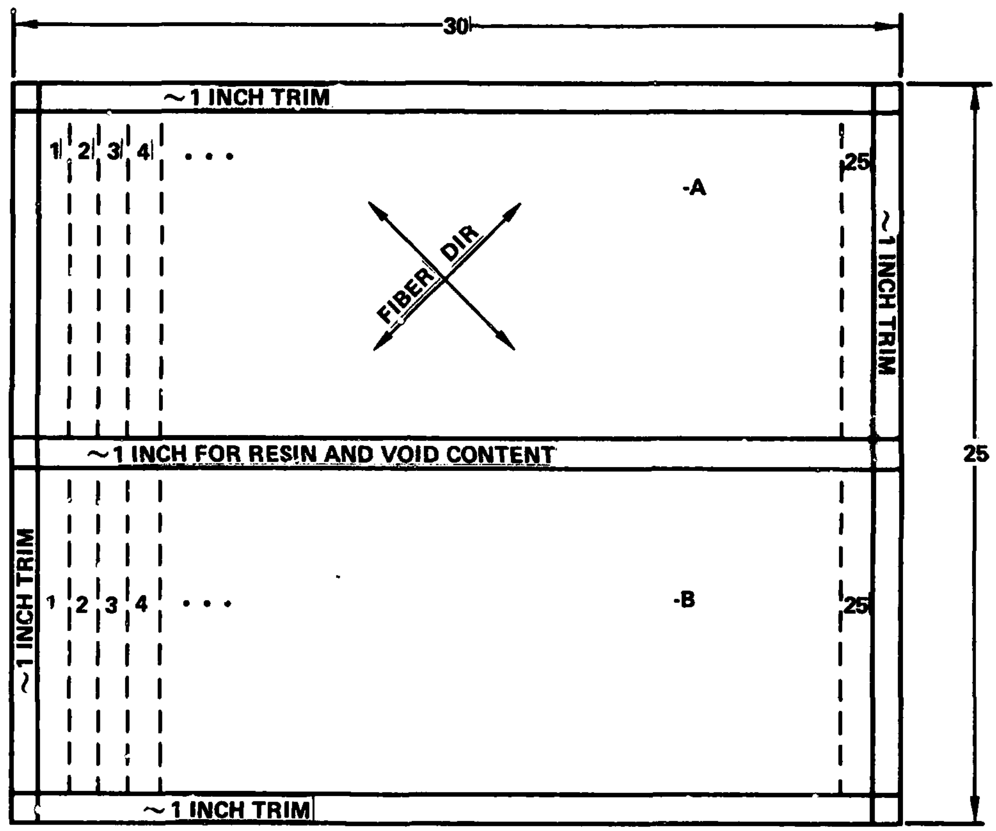


Figure B-4. - T300/5208 panel layout for laminate U2 100% - $\pm 45^{\circ}$ $(\pm 45)_{4S}$ - 16 plies.

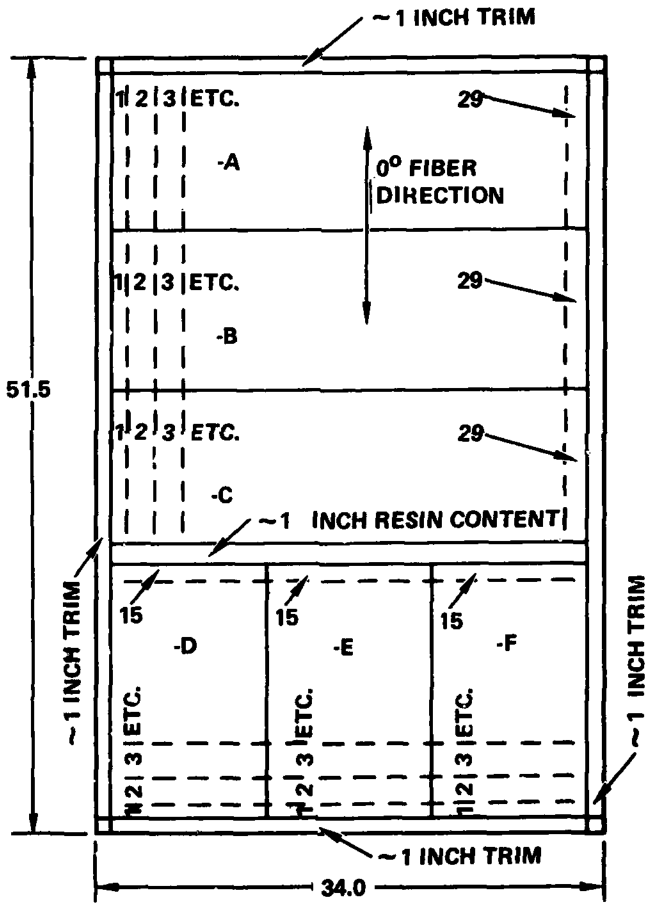


Figure B-5. - AS/3501-5A panel layout for laminate L1 quasi-isotropic $(0/45/90/-45_2/90/45/0)_S$ - 16 plies.

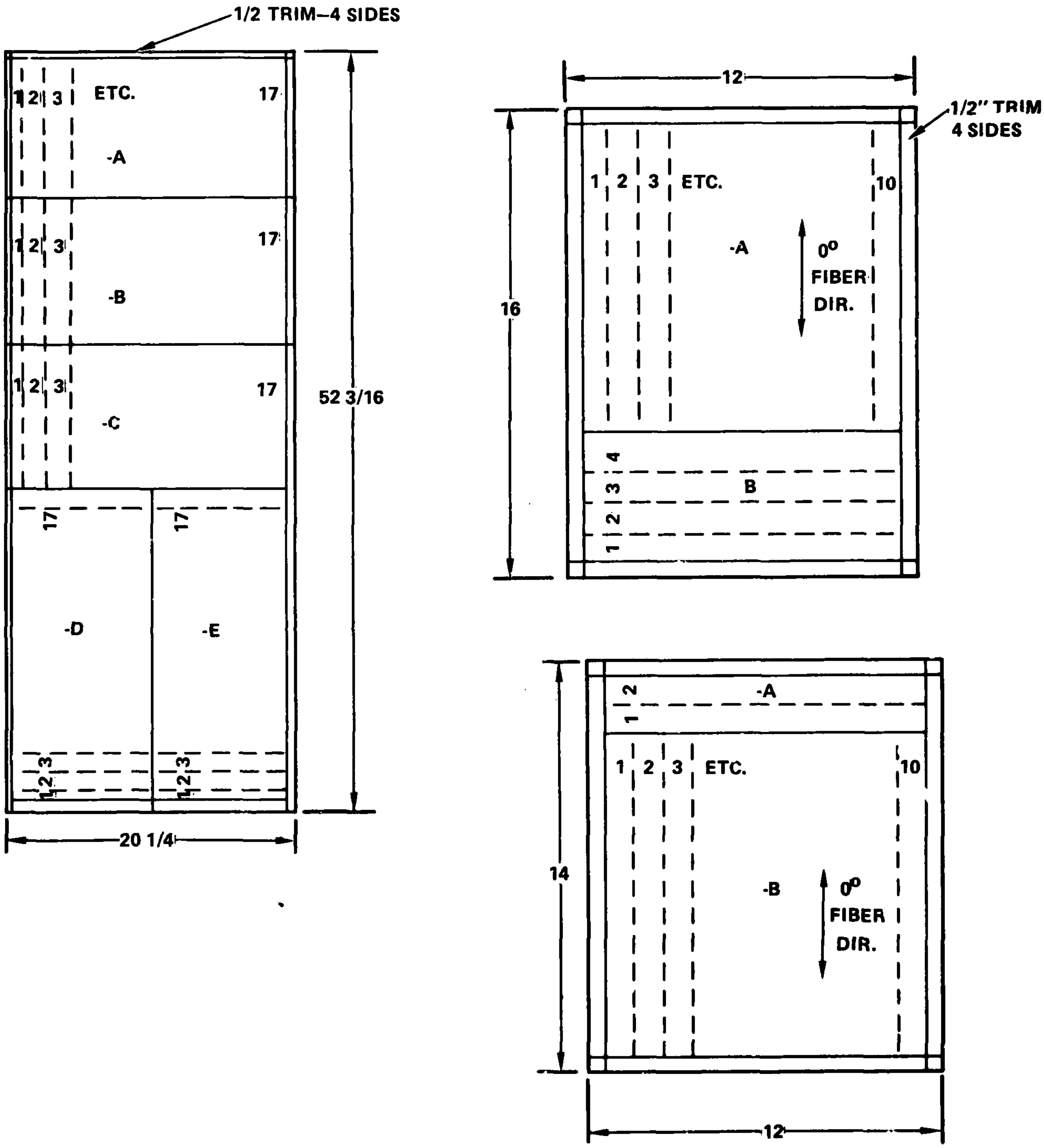


Figure B-6. - AS/3501-5A panel layouts for laminate L2 67% - 0°, 33% $\pm 45°$ $(0/45/0_2/-45/0_2/45/0_2/-45/0)_S$ - 24 plies.

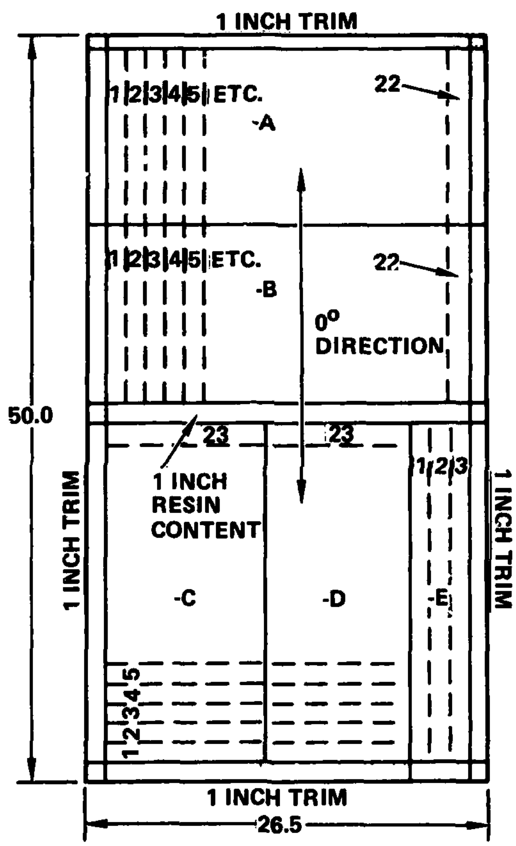


Figure B-7. - AS/3501-5A panel layout for laminate U1 100% - 0° unidirectional $(0^{\circ})_{16}$ - 16 plies.

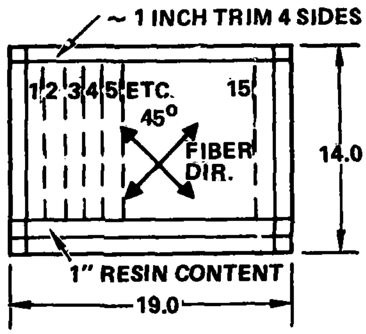


Figure B-8. - AS/3501-5A panel layout for laminate U2
100% $\pm 45^{\circ}$ $(\pm 45)_{4S}$ - 16 plies.

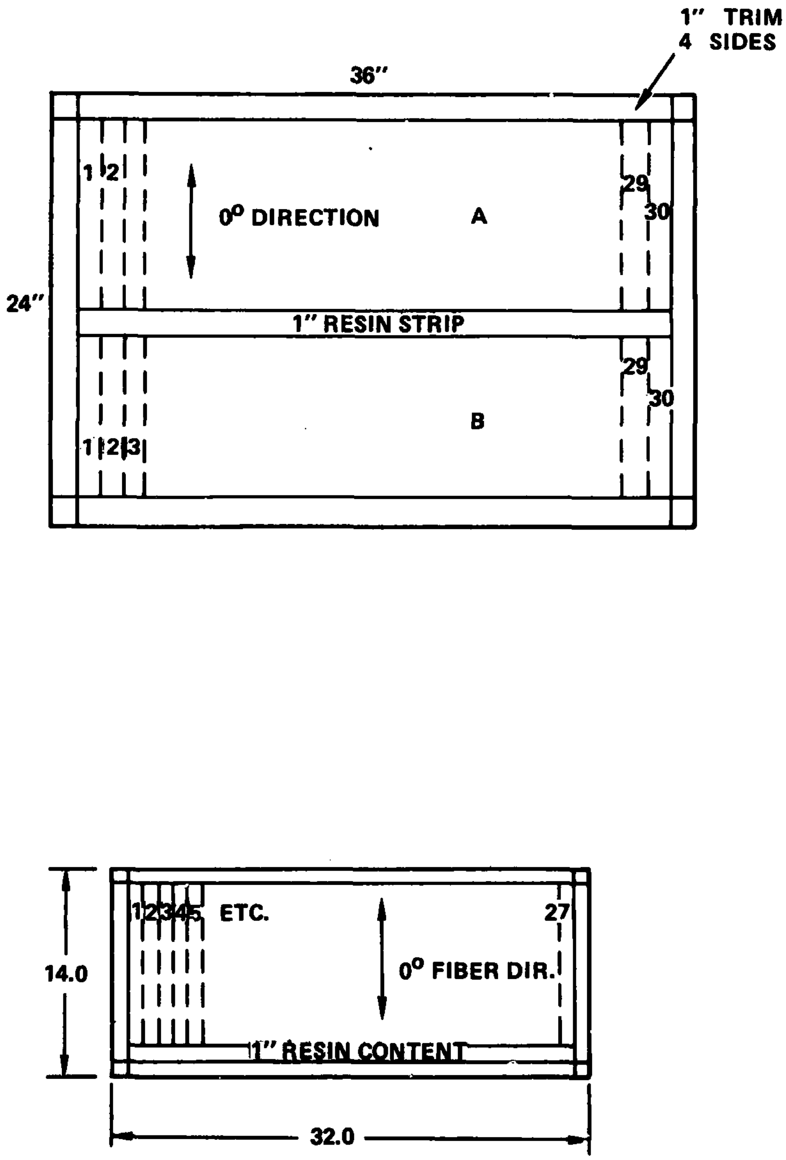
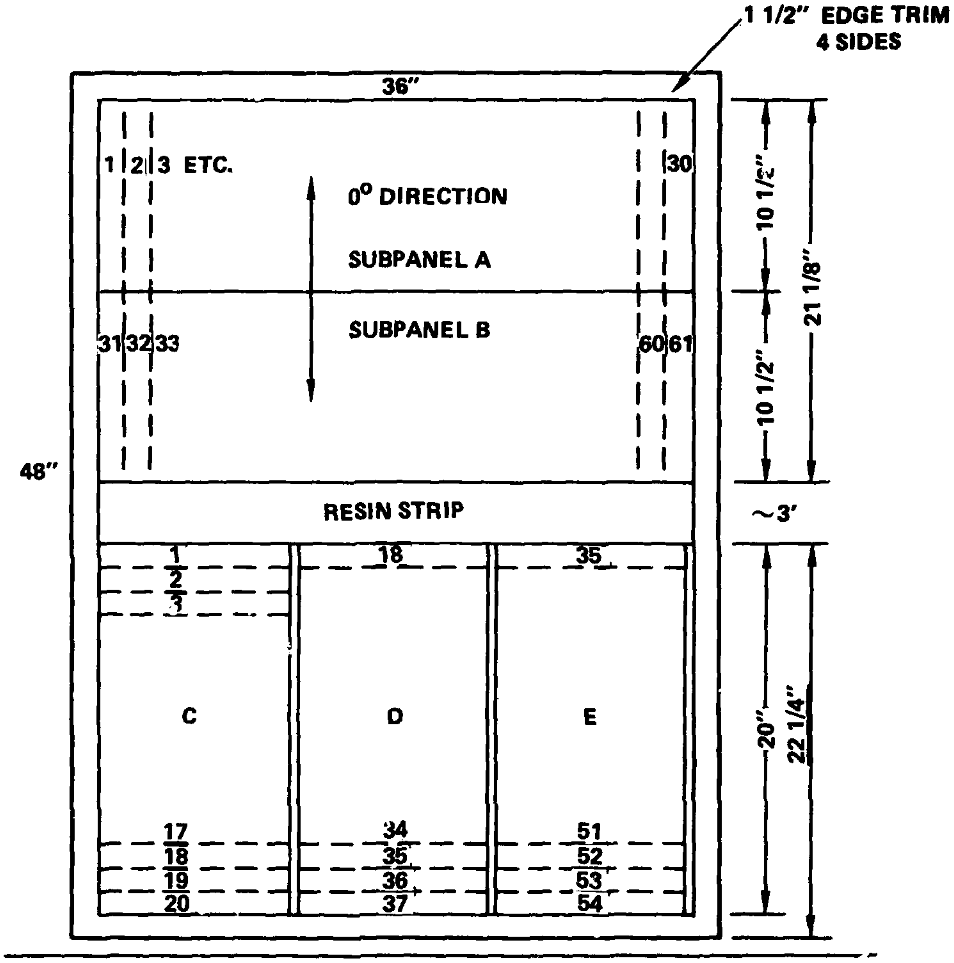


Figure B-9. - T300/5208 - batch SY panel layouts for laminate L1 quasi-isotropic $(0/45/90/-45_2/90/45/0)_S$ - 16 plies.



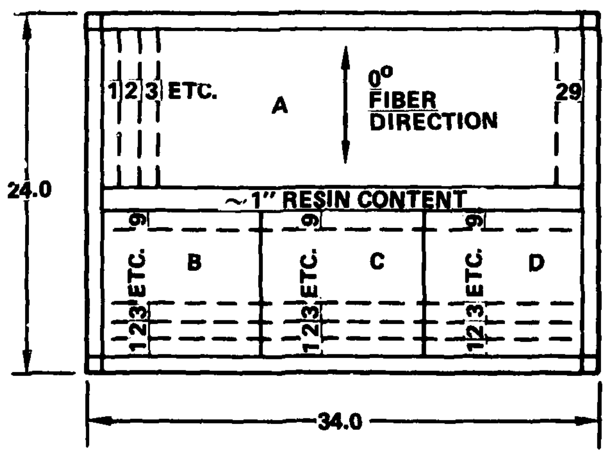


Figure B-10. - T300/5208 batch SY panel layouts for laminate L2 67% - 0°, 33% ±45° $(0/45/0_2/-45/0_2/45/0_2/-45/0)_S$ - 24 plies.

APPENDIX C

MOISTURE DISTRIBUTIONS

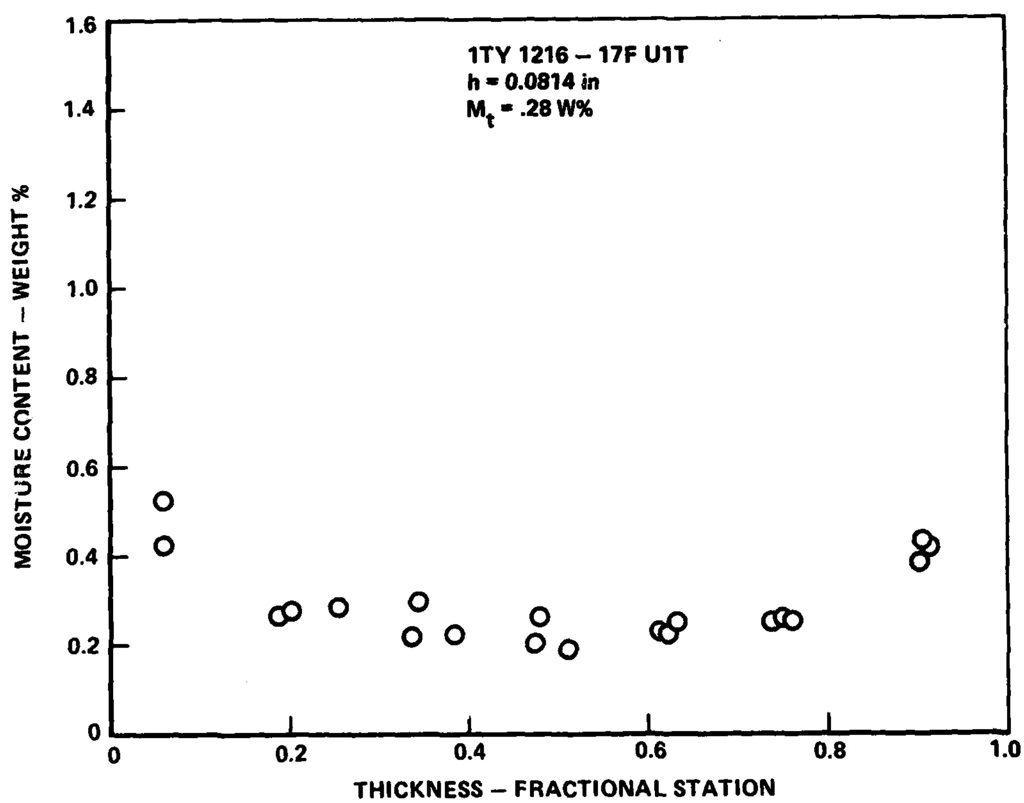


Figure C-1. - Moisture distribution after 14 days at 40% RH and 22°C (72°F).

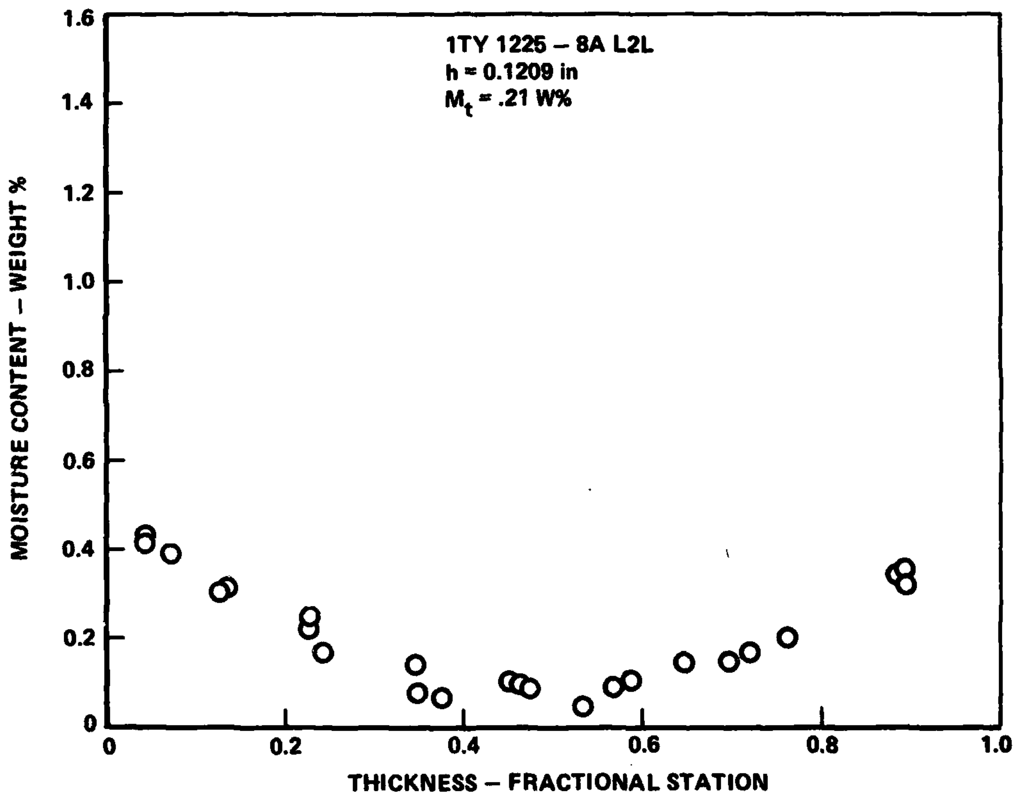


Figure C-2. - Moisture distribution after 90 days at 40% RH and 22°C (72°F).

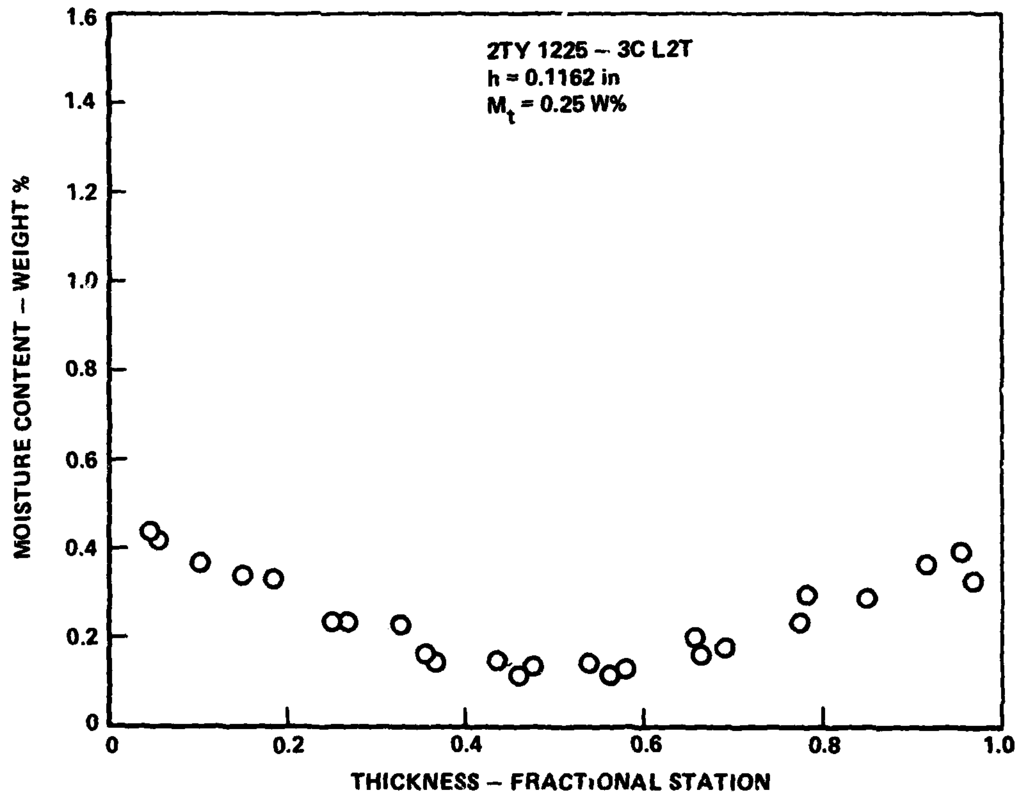


Figure C-3. - Moisture distribution after 90 days at 40% RH and 22°C (72°F).

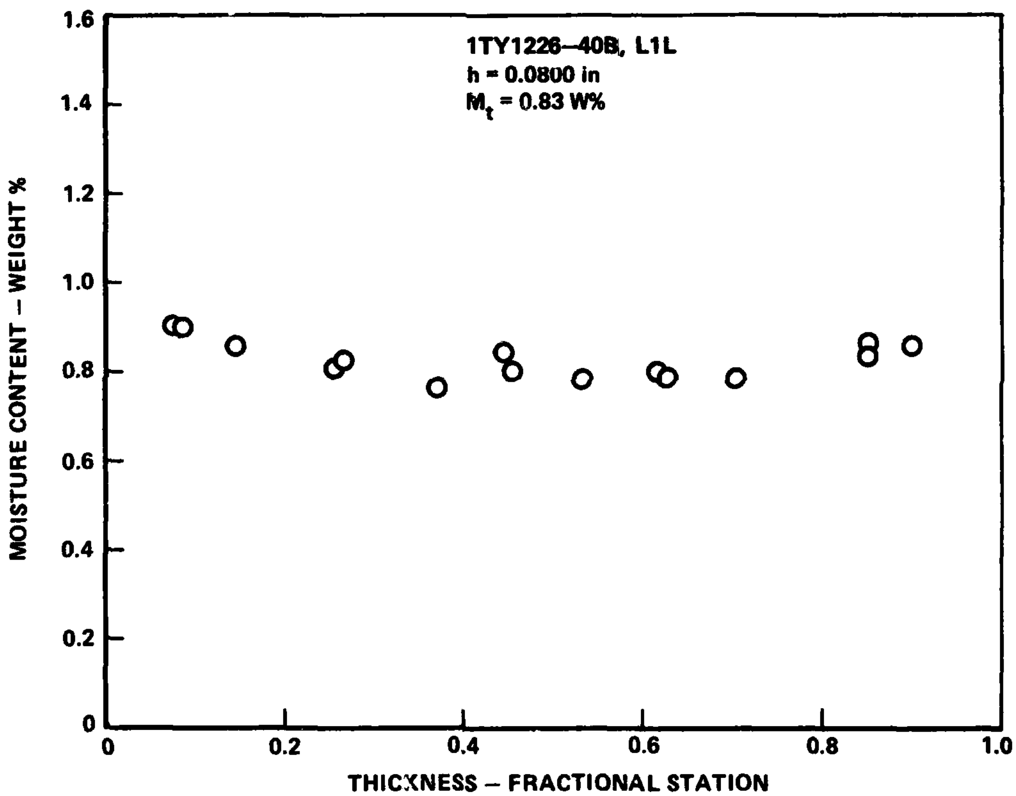


Figure C-4. - Moisture distribution after 90 days at 90% RH and 82°C (180°F) - T300/5208.

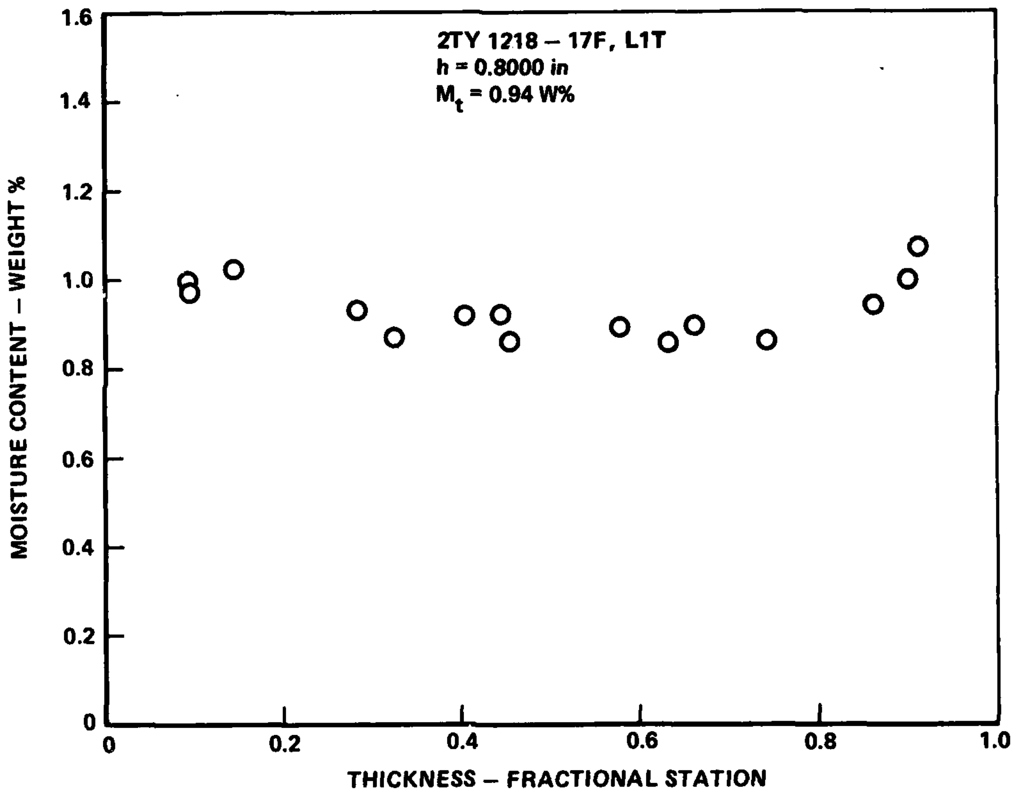


Figure C-5. - Moisture distribution after 90 days at 90% RH and 82°C (180°F) - T300/5208.

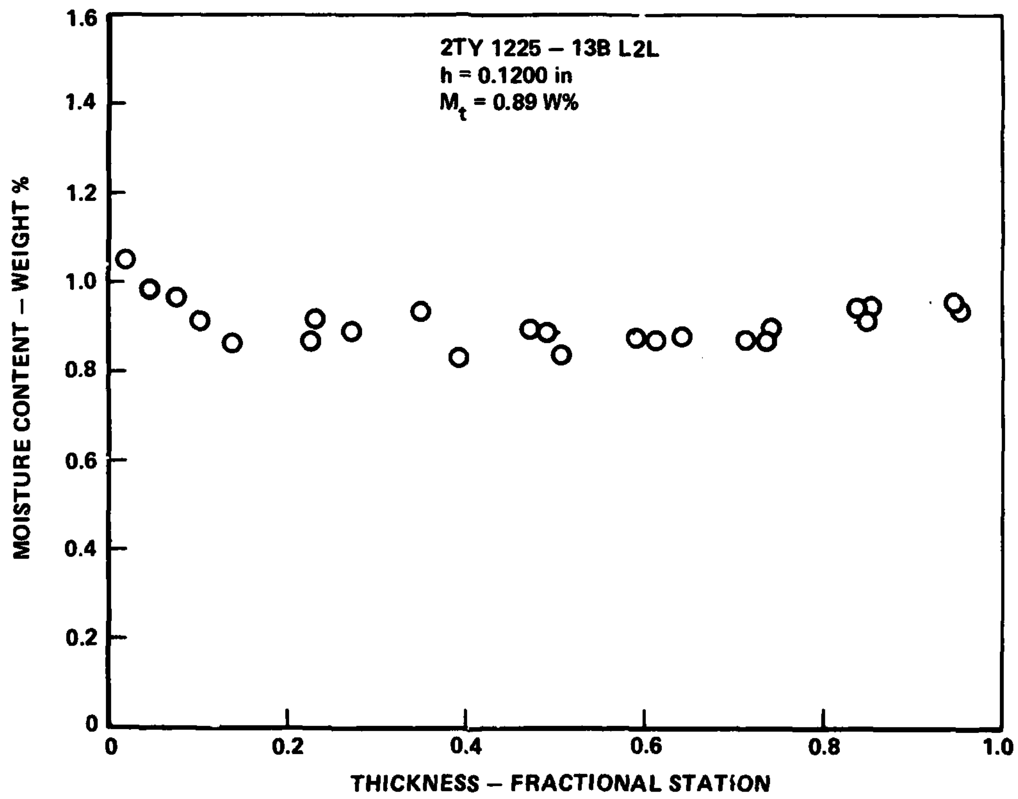


Figure C-6. - Moisture distribution after 90 days at 90% RH and 82°C (180°F) - T300/5208.

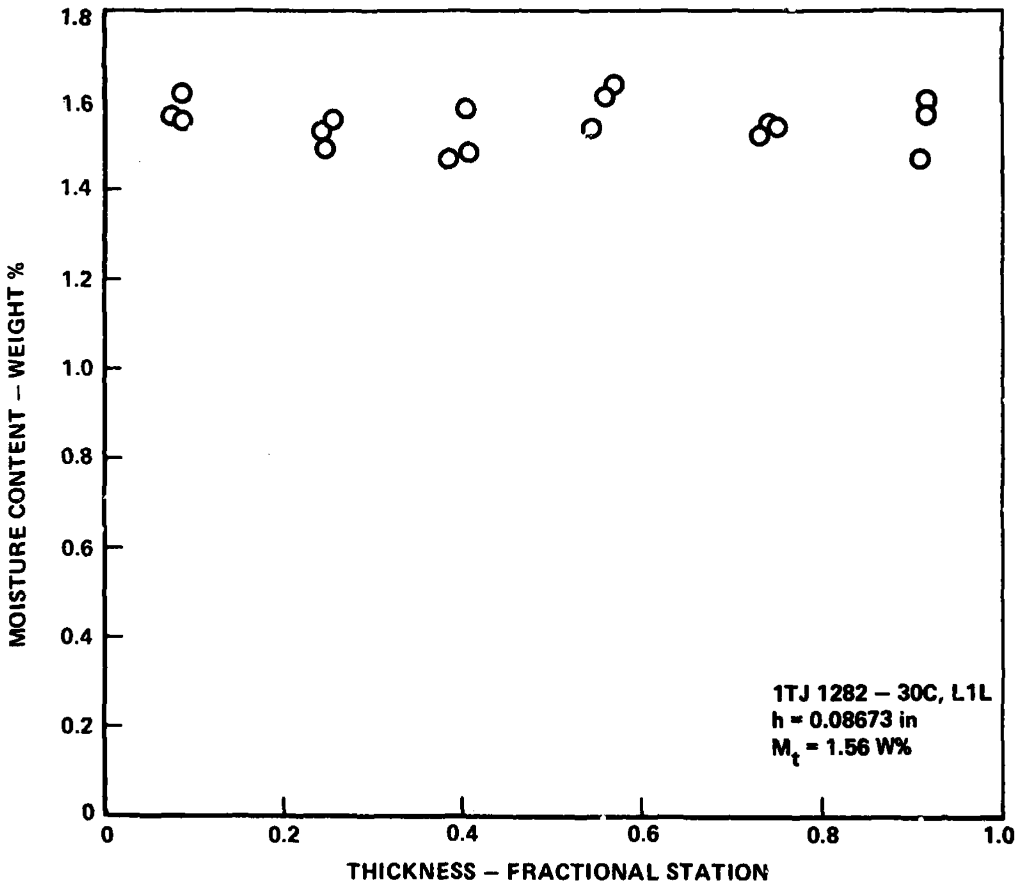


Figure C-7. - Moisture distribution after 90 days at 90% RH and 82°C (180°F) - AS/3501-5A.

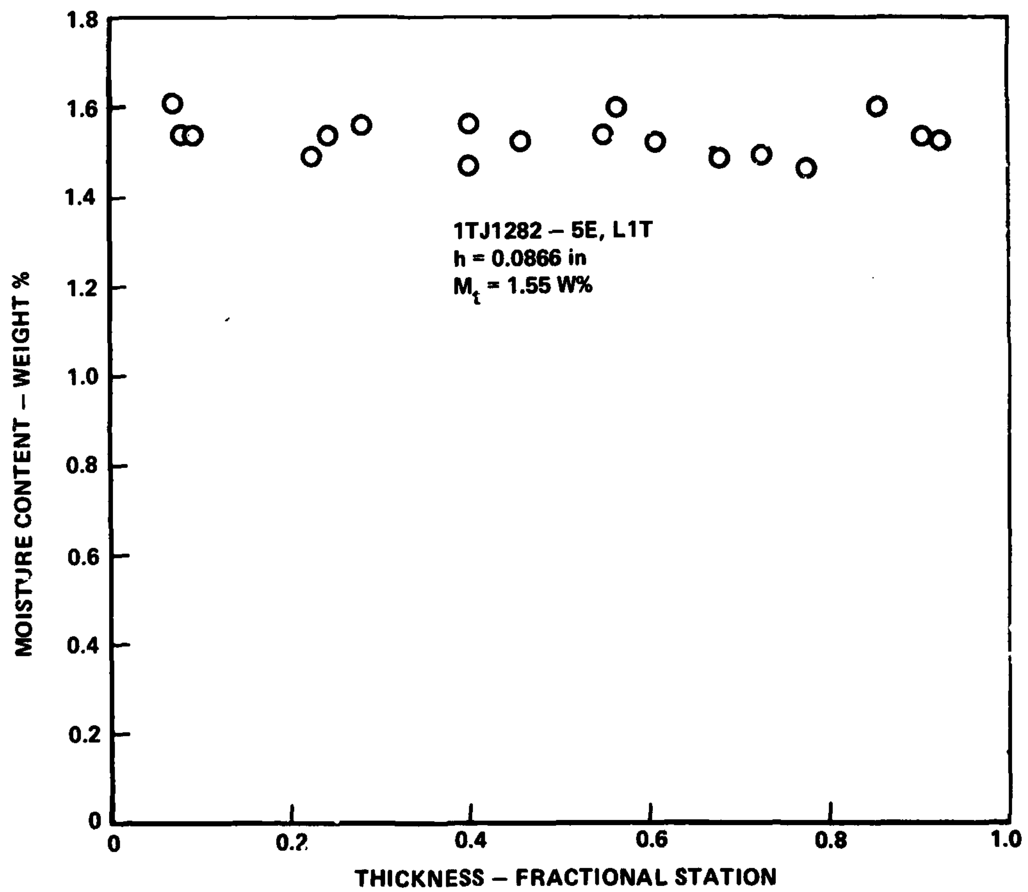


Figure C-8. - Moisture distribution after 90 days at 90% RH and 82°C (180°F) - AS/3501-5A.

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THE EFFECT OF ENVIRONMENT ON THE COMPRESSIVE STRENGTHS OF LAMIN--ETC(U)
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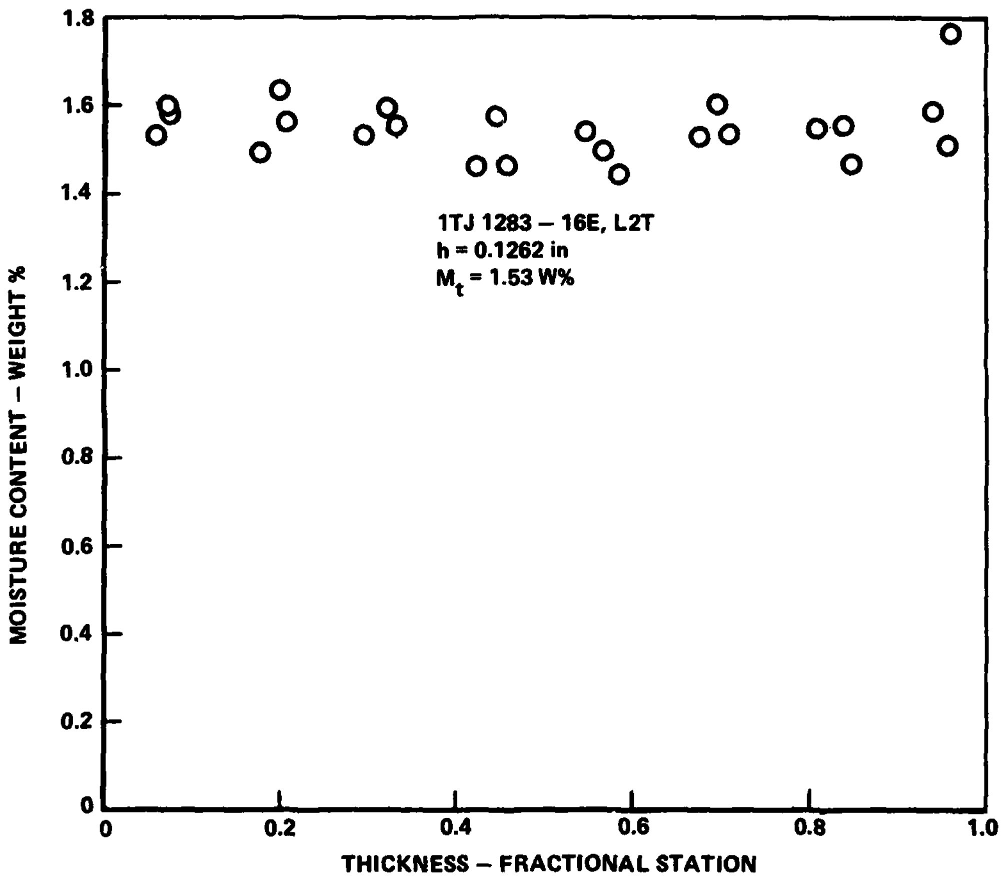


Figure C-9. - Moisture distribution after 90 days at 90% RH and 82°C (180°F) - AS/3501-5A.

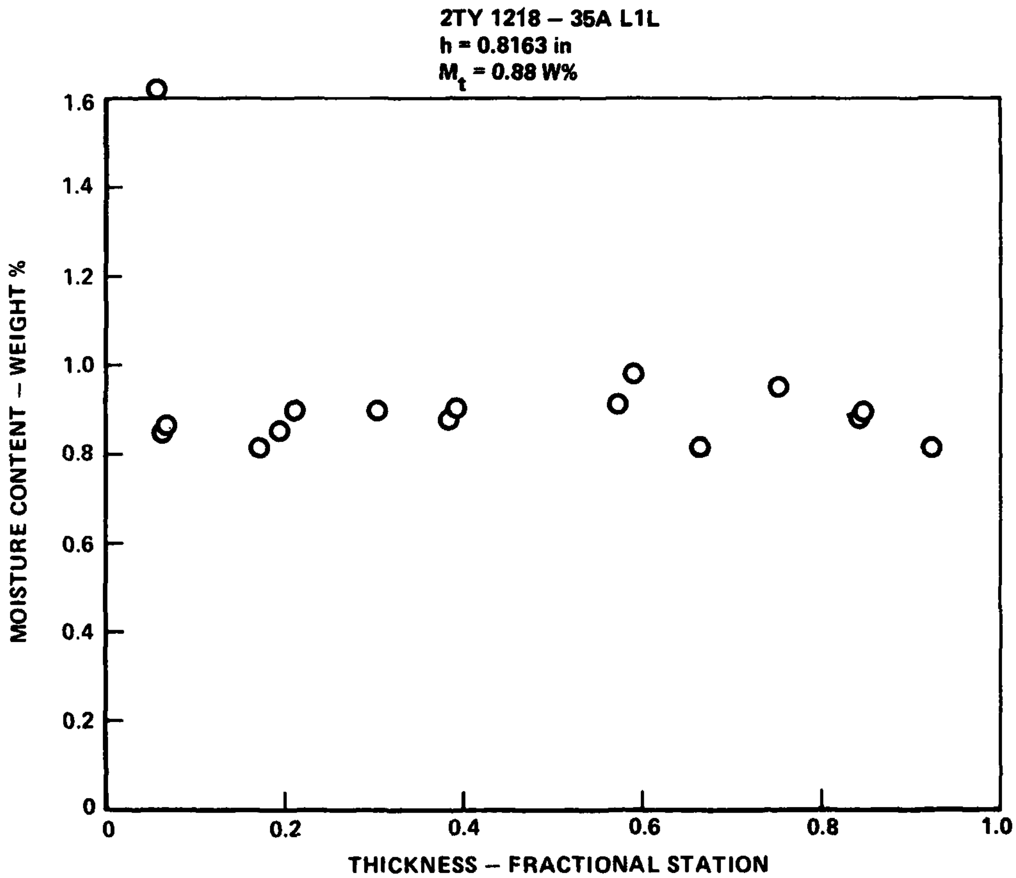


Figure C-10. - Moisture distribution after testing at two column lengths at 93°C (200°F) - T300/5208.

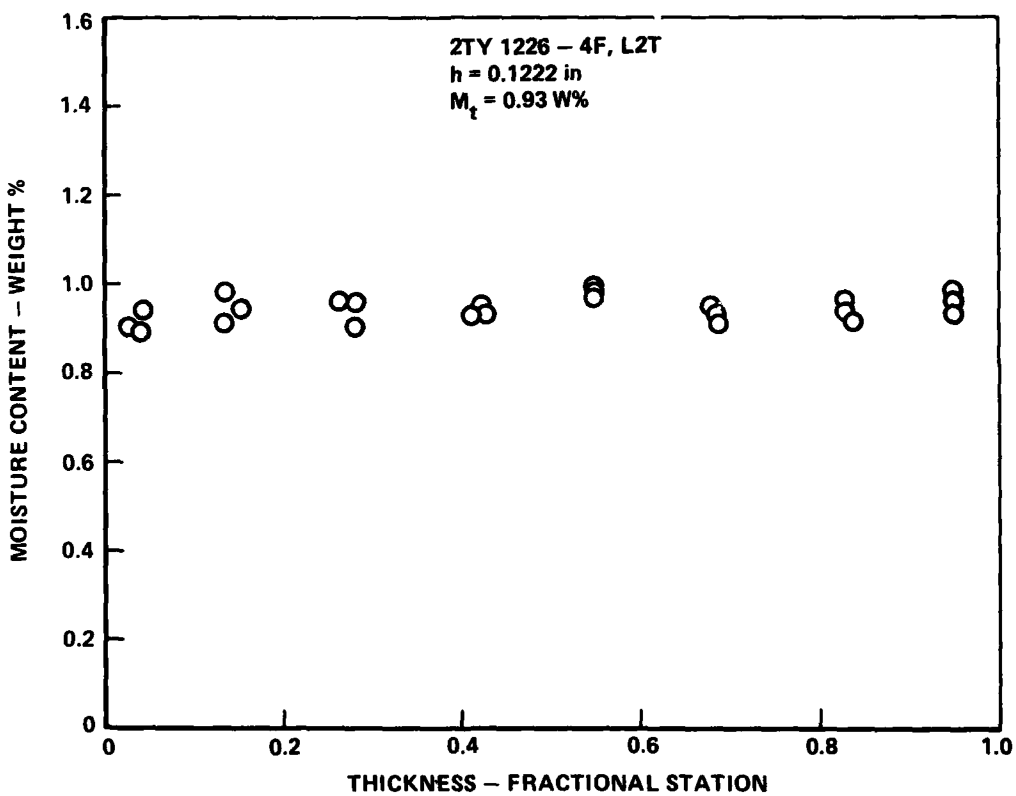


Figure C-11. - Moisture distribution after testing at two column lengths at 93°C (200°F) - T300/5208.

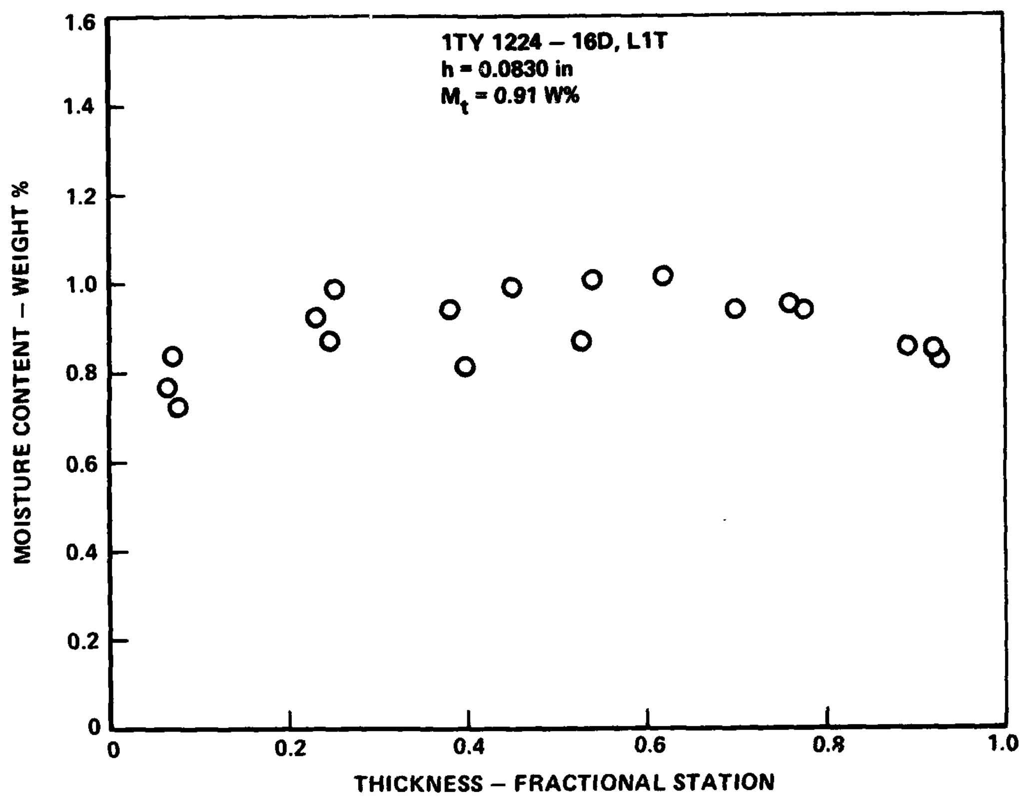


Figure C-12. - Moisture distribution after testing at two column lengths at 135°C (275°F) - T300/5208.

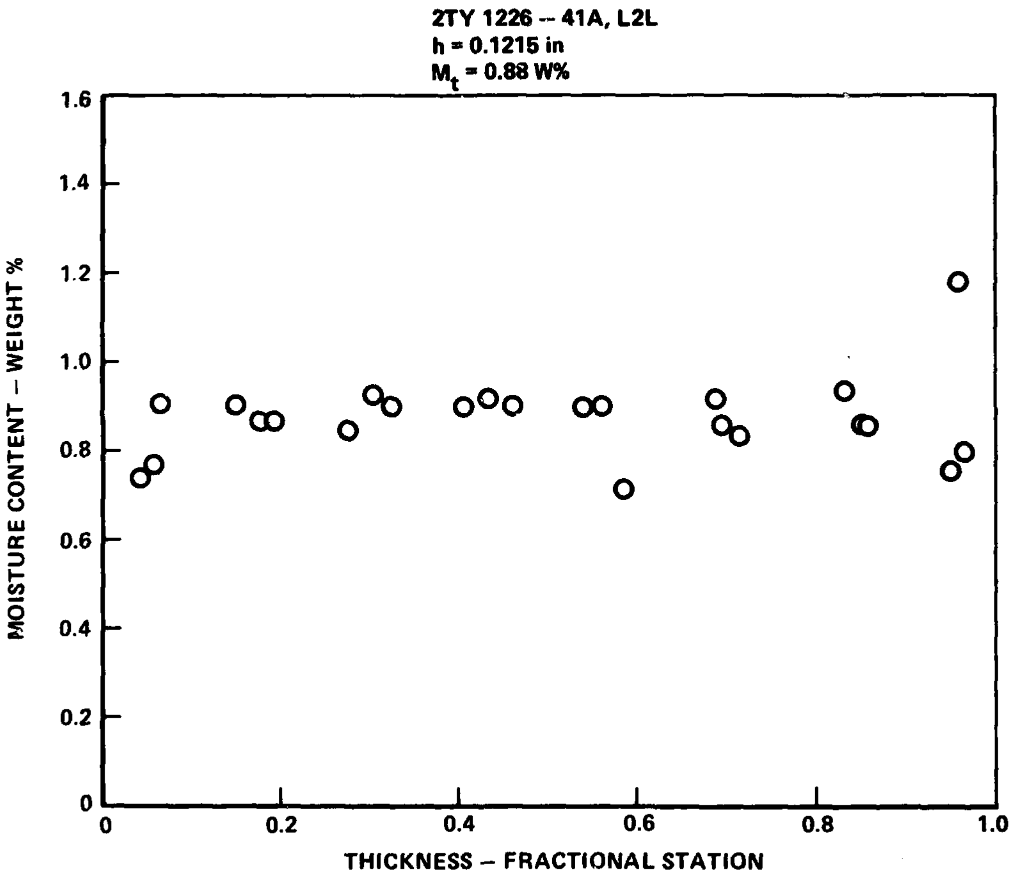


Figure C-13. - Moisture distribution after testing at two column lengths at 135°C (275°F) - T300/5208.

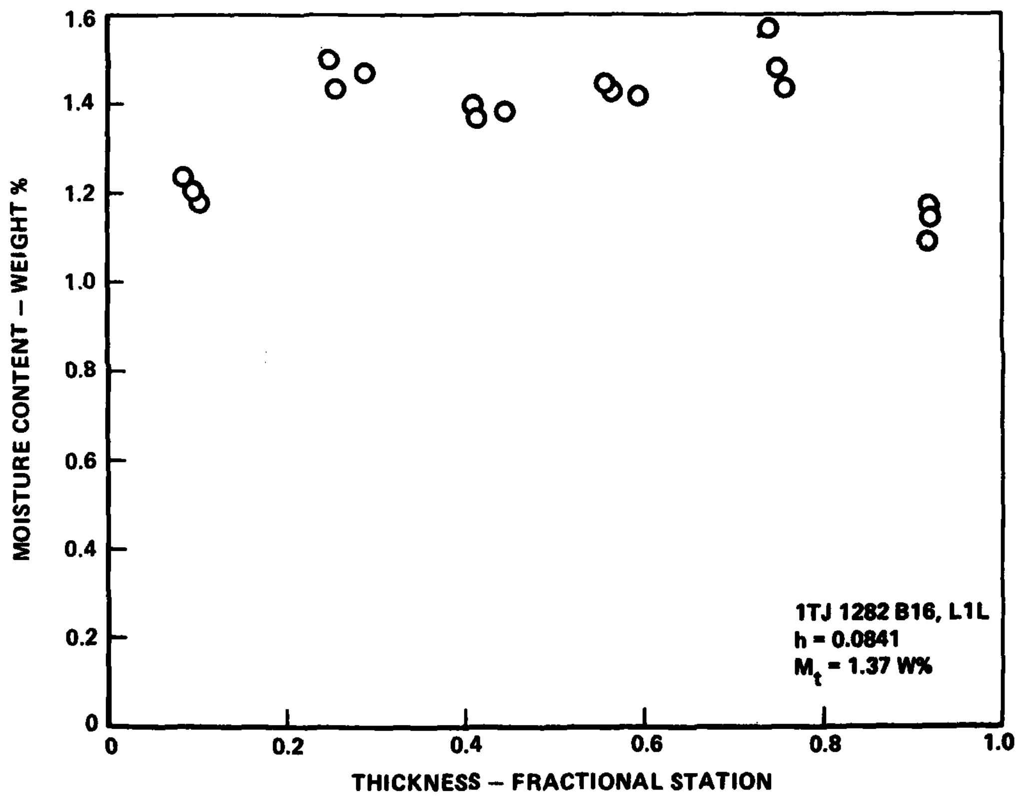


Figure C-14. - Moisture distribution after testing at two column lengths at 135°C (275°F) - AS/3501-5A.

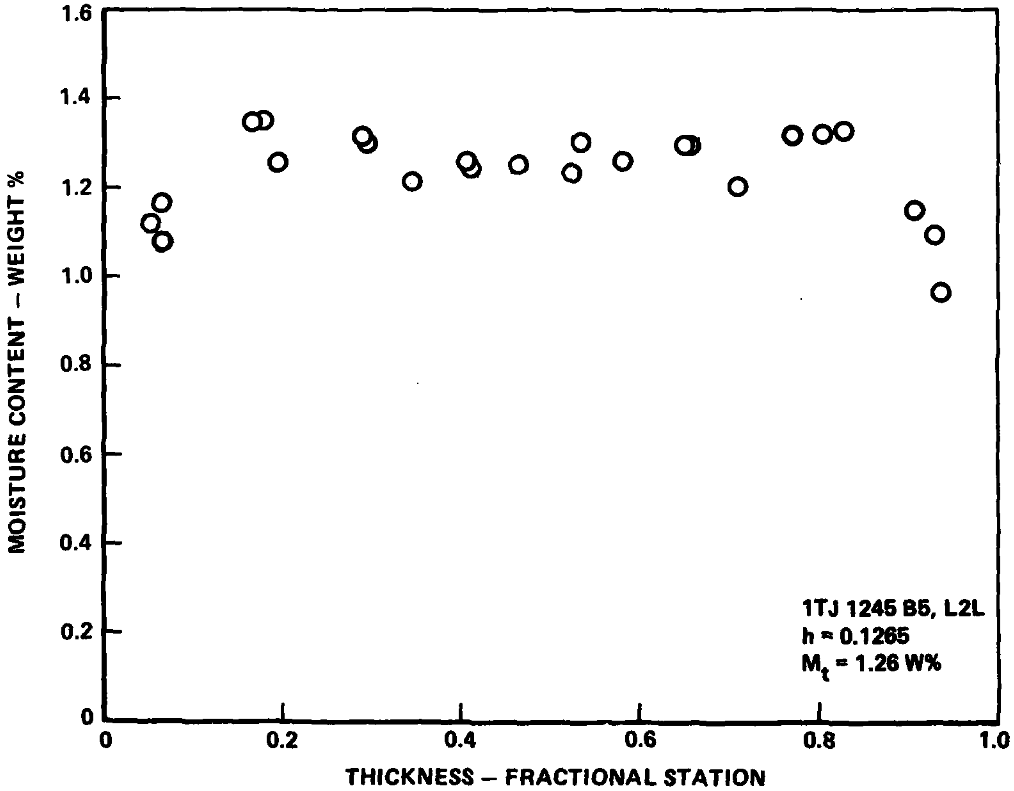


Figure C-15. - Moisture distribution after testing at two column lengths at 135°C (275°F) - AS/3501-5A.

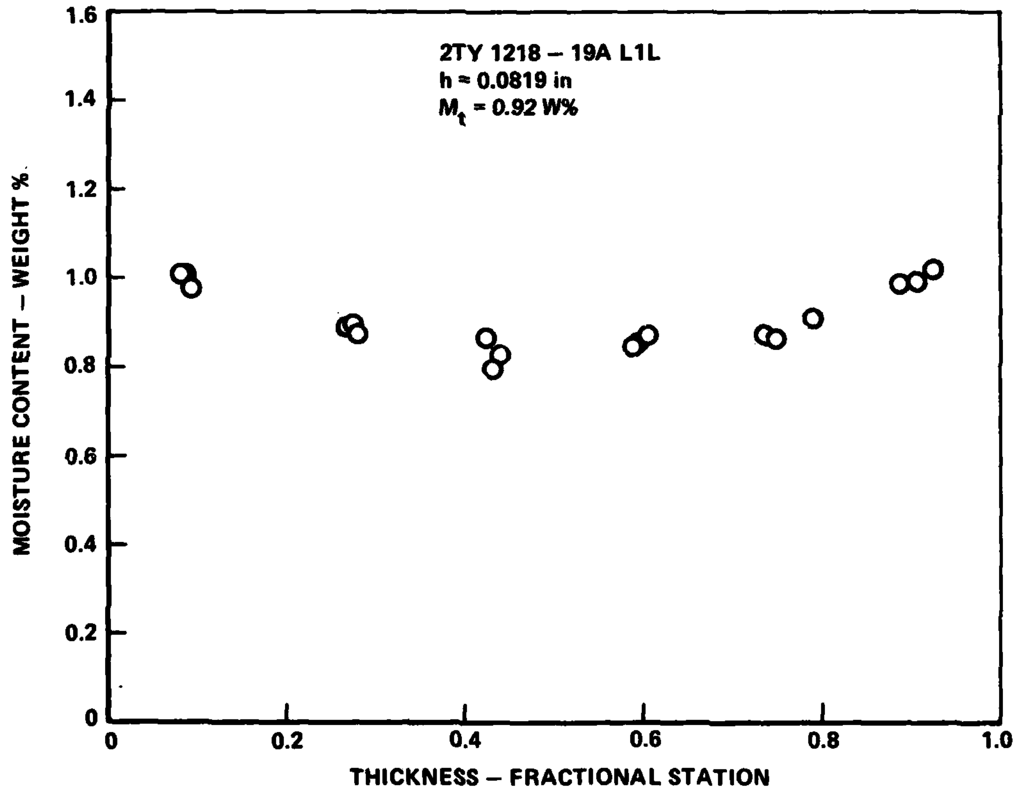


Figure C-16. - Parabolic non-uniform moisture distribution obtained after one week at 90% RH and 82°C (180°F) - T300/5208.

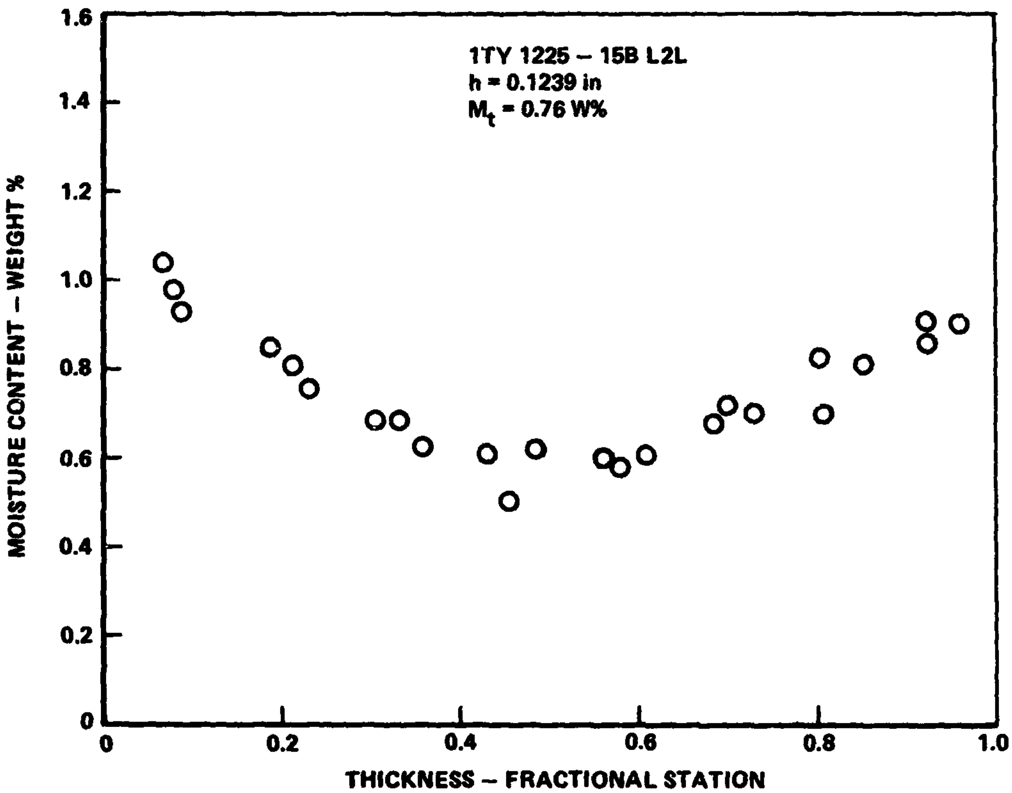


Figure C-17. - Parabolic non-uniform moisture distribution obtained after one week at 90% RH and 82°C (180°F) - T300/5208.

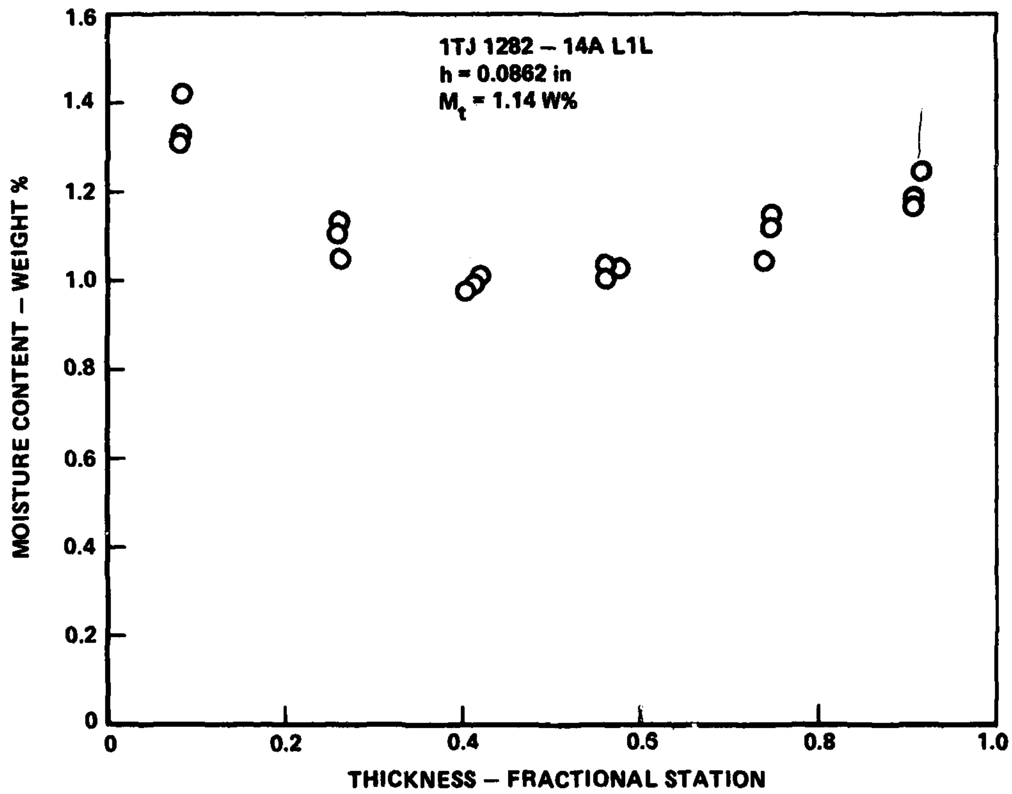


Figure C-18. - Parabolic non-uniform moisture distribution obtained after one week at 90% RH and 82°C (180°F) - AS/3501-5A.

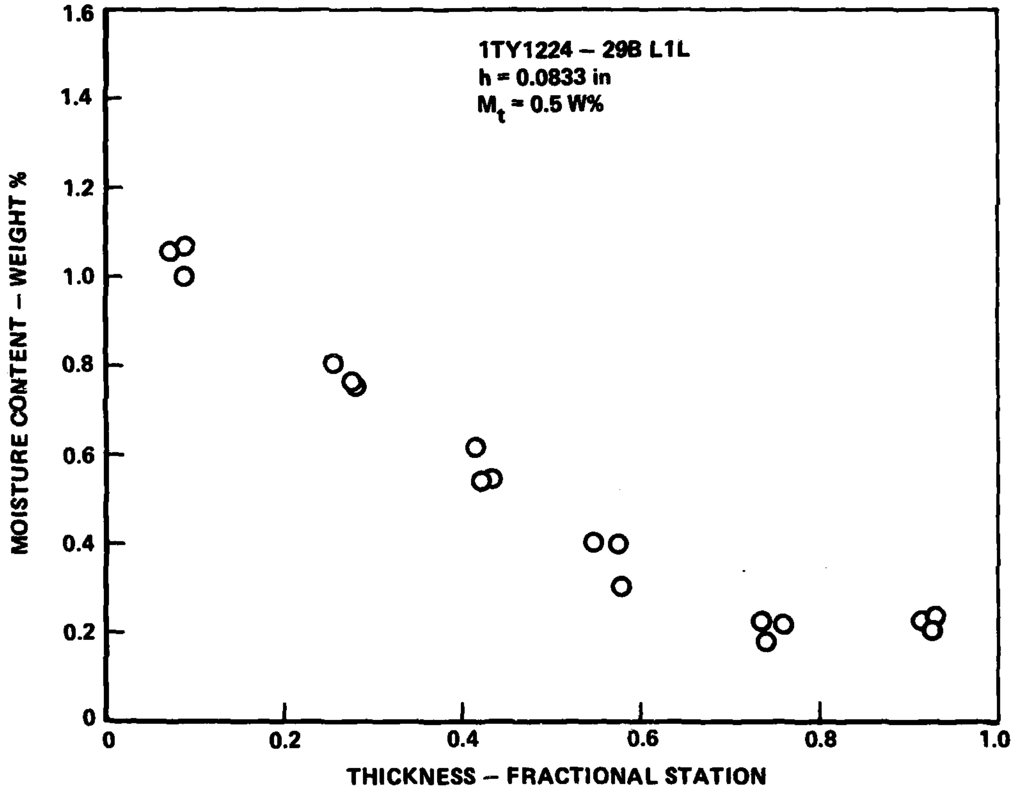


Figure C-19. - Linear non-uniform moisture distribution obtained after one week at 90% RH and 82°C (180°F) - T300/5208.

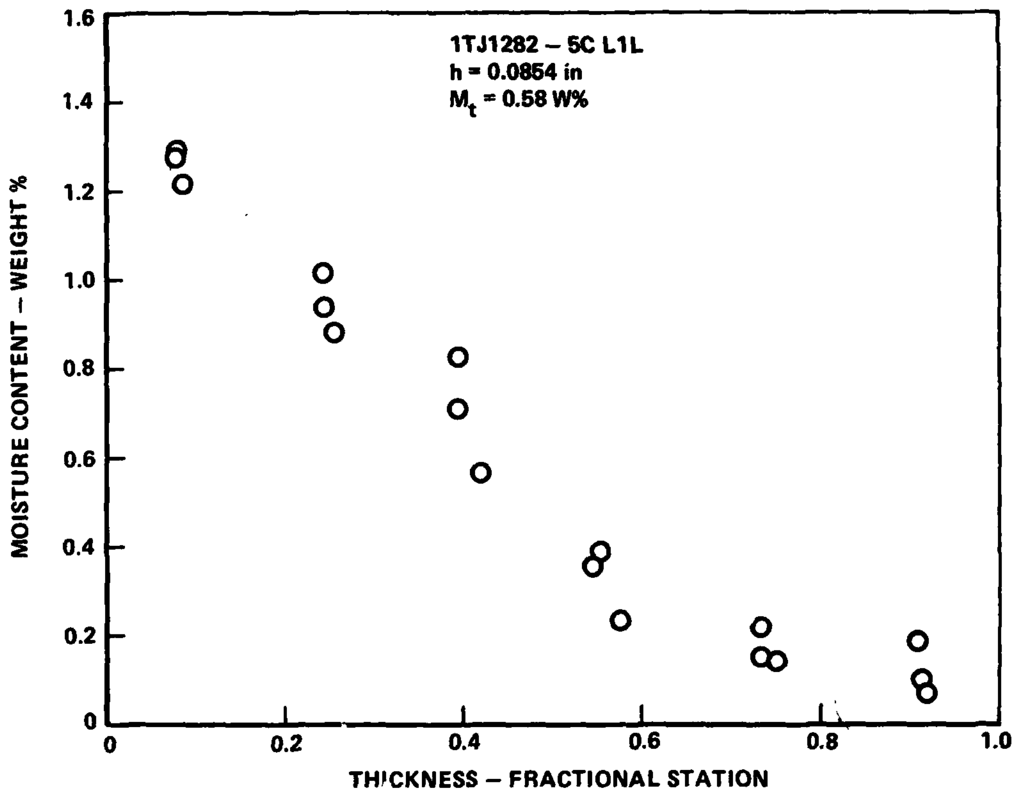


Figure C-20. - Linear non-uniform moisture distribution obtained after one week at 90% RH and 82°C (180°F) - AS/3501-5A.

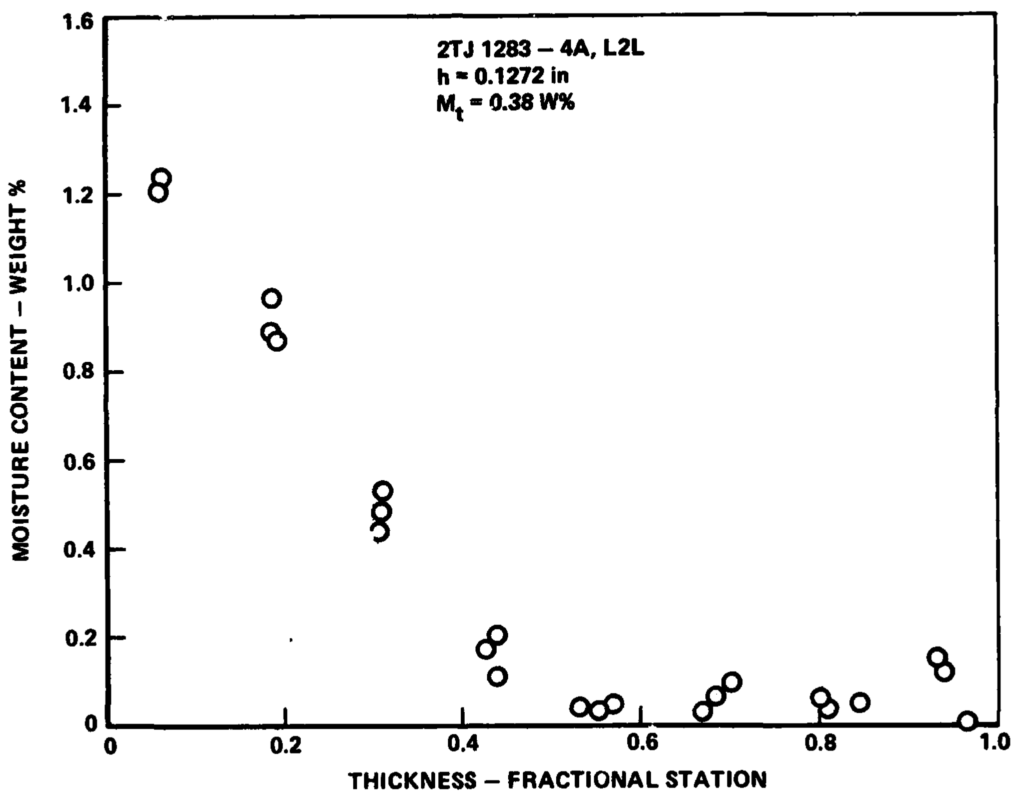


Figure C-21. - Linear non-uniform moisture distribution obtained after one week at 90% RH and 82°C (180°F) - AS/3501-5A.

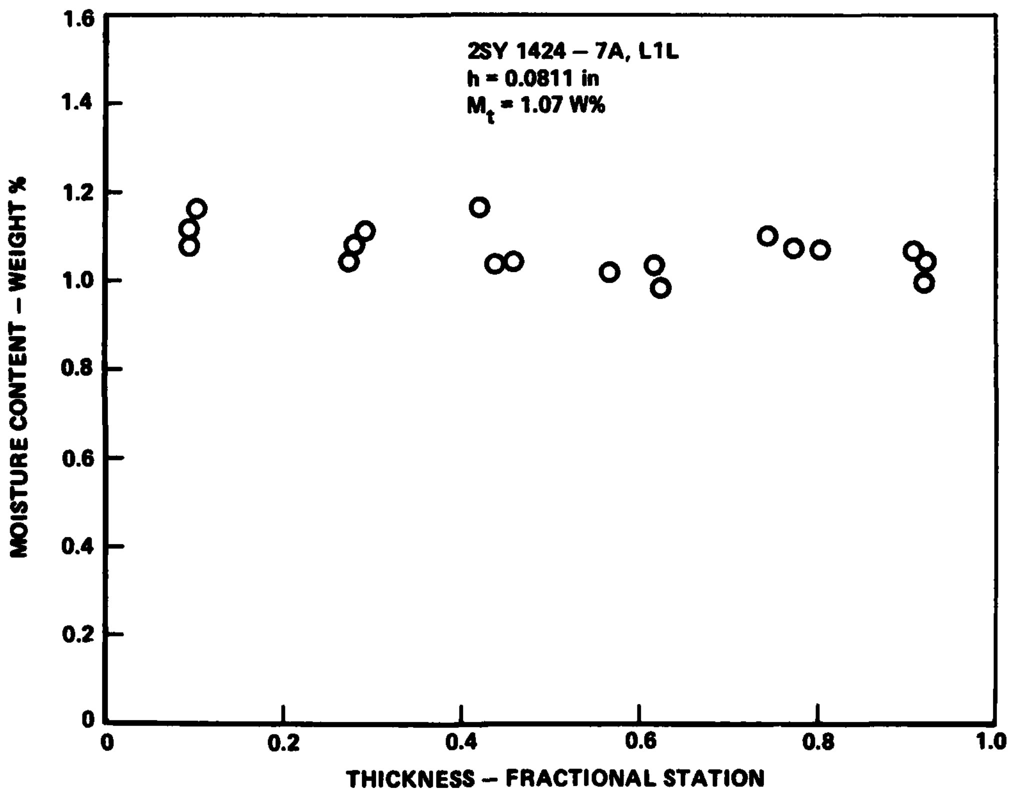


Figure C-22. - Moisture distribution in specimen preloaded in tension to 80% σ_{TU} after 70 days at 82°C (180°F) and 90% RH - T300/5208

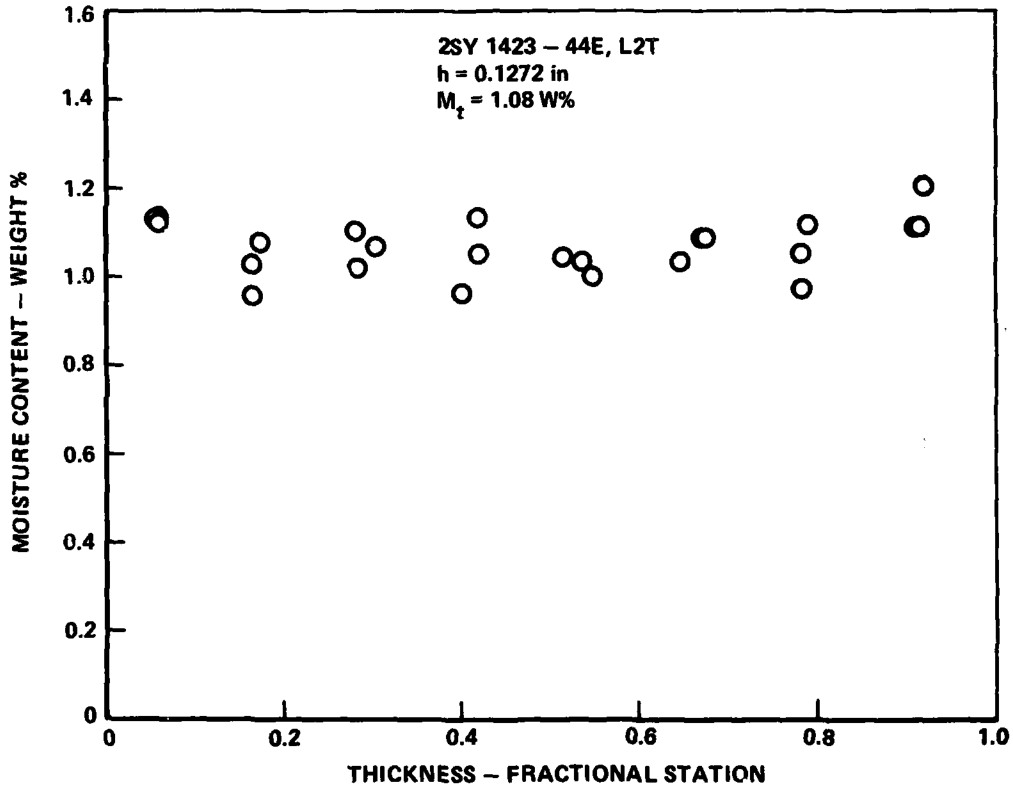


Figure C-23. - Moisture distribution in specimen preloaded in tension to 80% σ_{TU} after 70 days at 82°C (180°F) and 90% RH - T300/5208

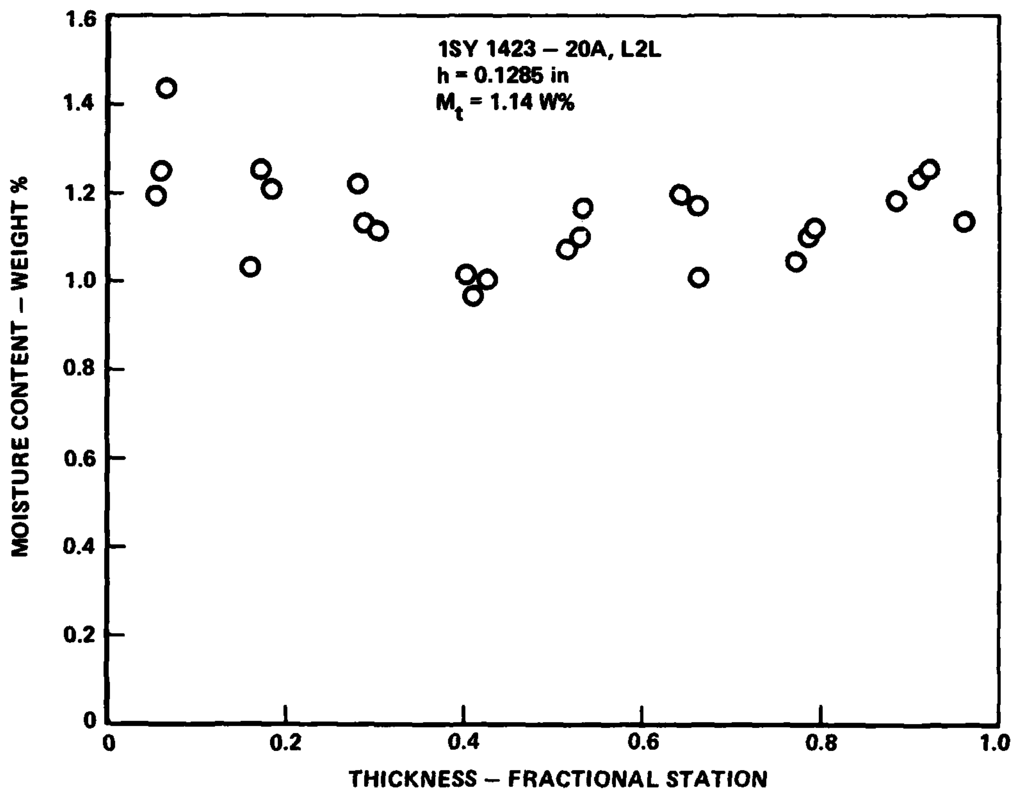


Figure C-24. - Moisture distribution in specimen preloaded in tension to 90% σ_{TU} after 70 days at 82°C (180°F) and 90% RH - T300/5208

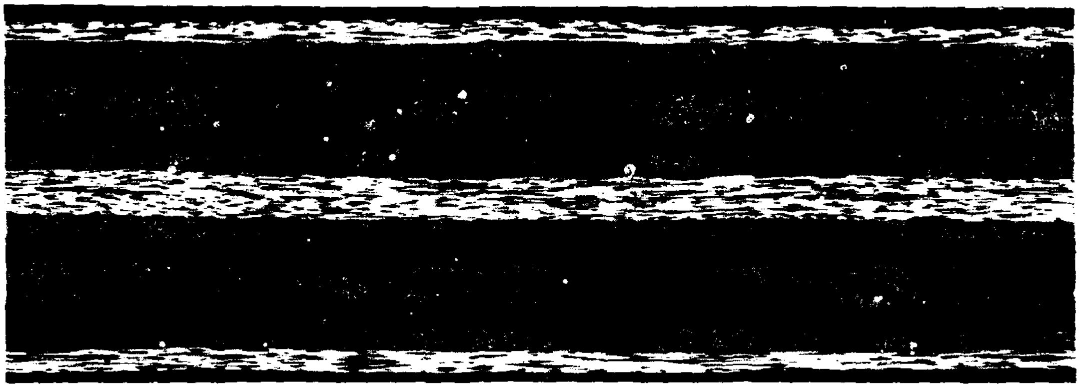
APPENDIX D

PHOTOMICROGRAPHIC STUDY

OF MICROCRACKED SPECIMENS

Twelve Specimens of each of laminates L1L, L2L and L2T of T300/5208, batch SY were loaded in tension to 80% of the average tensile ultimate strength as determined in Section 4.4. An additional twelve specimens of L2L were loaded to 90% of σ_{TU}. After unloading, half of these were subjected to moisture conditioning at 90% RH and 82°C (180°F) for a minimum of 10 weeks. Both dry and wet specimens were then tested under column loading conditions.

Selected specimens were inspected by optical microscopy. Six adjacent longitudinal sections were cut along the specimen centerline such that the entire six-inch gage length could be inspected. Transverse mounts were also inspected at Sections 4 and 5. No cracks could be located in the L2L laminates. Typical Sections are presented in Figures D-1 - D-17.



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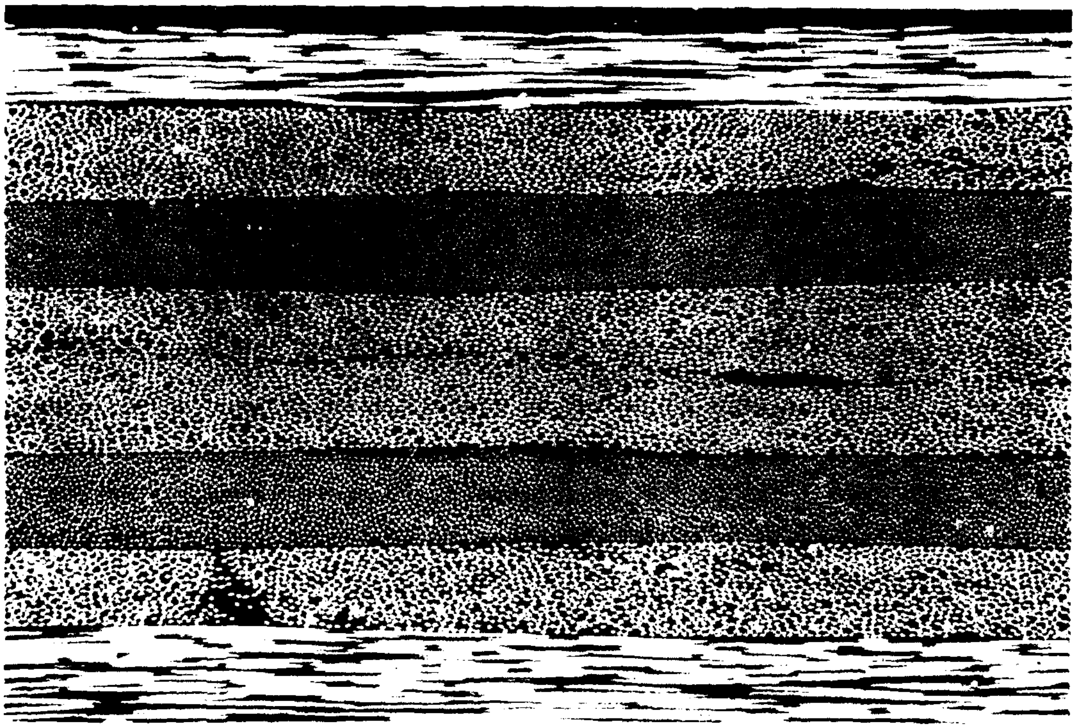

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Figure D-1. - Longitudinal sections of area 1 of dry quasi-isotropic L1L specimen 2SY1424-32B loaded to 80% of σ_{TU}.

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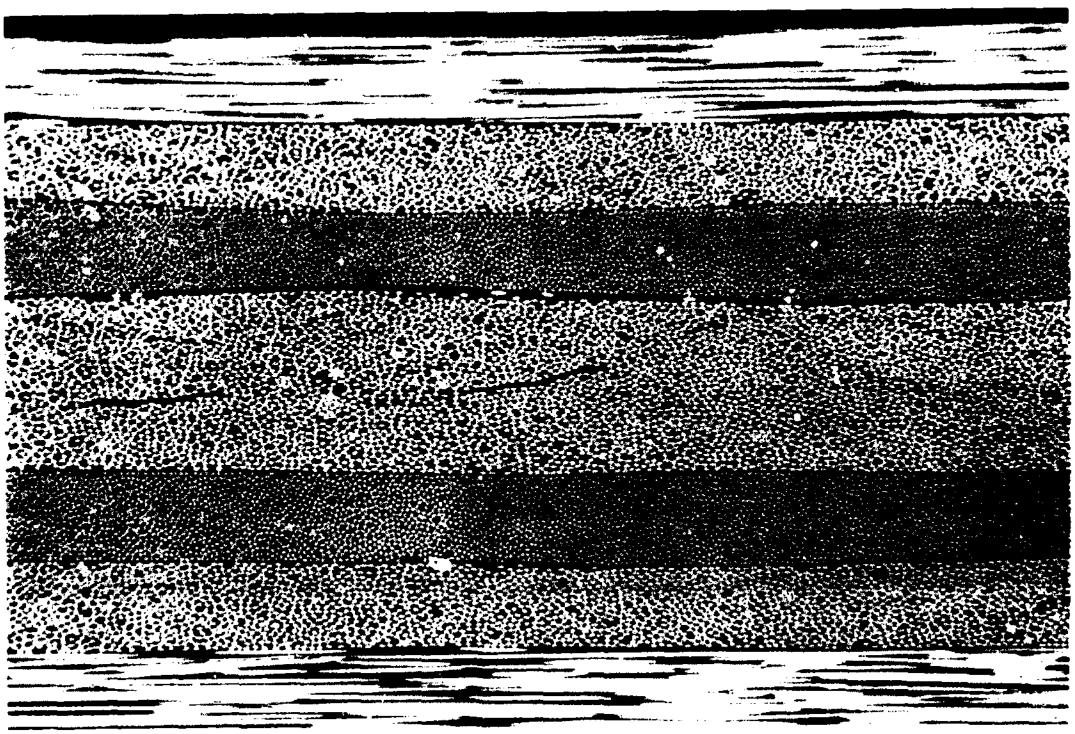

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Figure D-2. - Longitudinal sections of area 3 of dry quasi-isotropic L1L specimen 2SY1424-32B loaded to 80% of σ_{TU}.

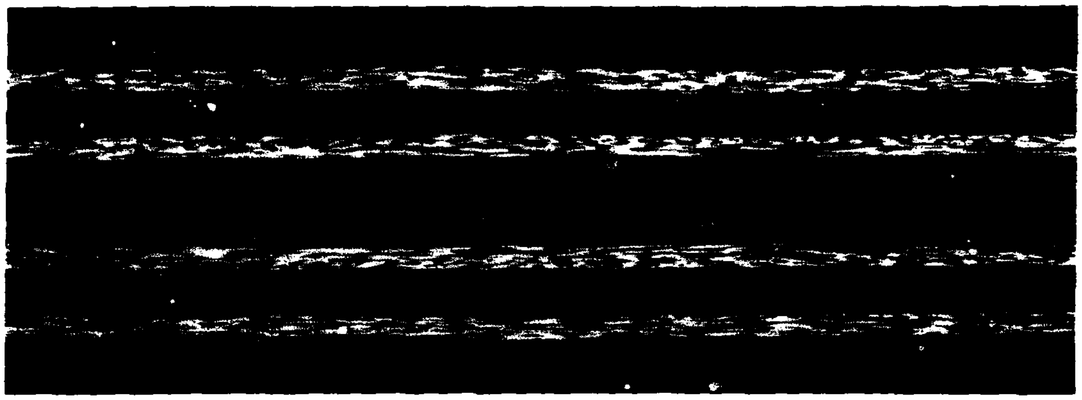

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Figure D-3. - Transverse section of area 4 of dry quasi-isotropic L1L specimen 2SY1424-32B loaded to 80% of σ_{TU} - no cracking evident.

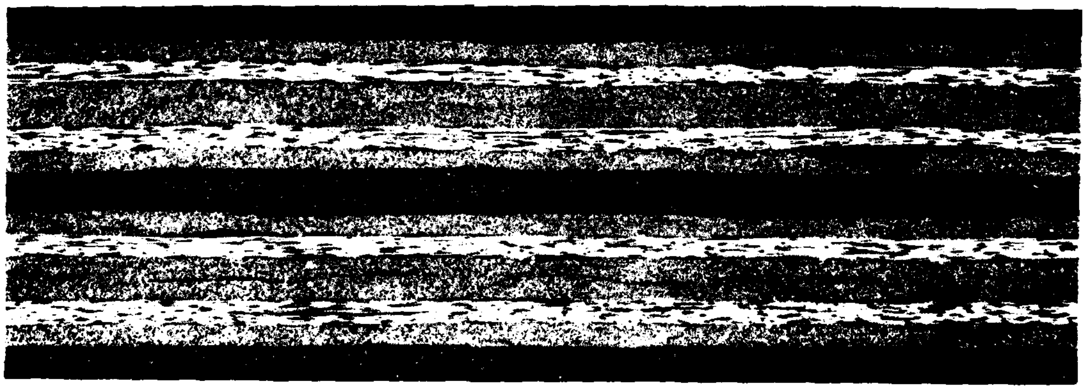

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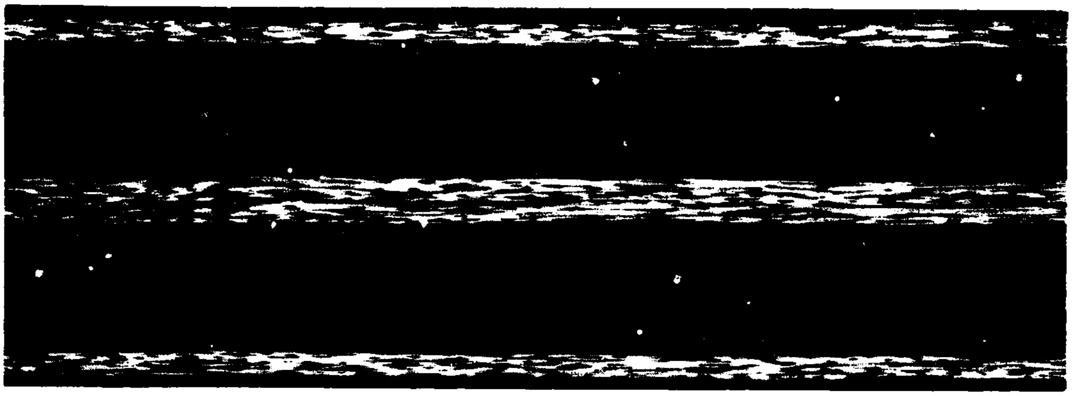
Figure D-4. - Transverse section of area 5 of dry quasi-isotropic L1L specimen 2SY1424-32B loaded to 80% of σ_{TU} - no cracking evident.



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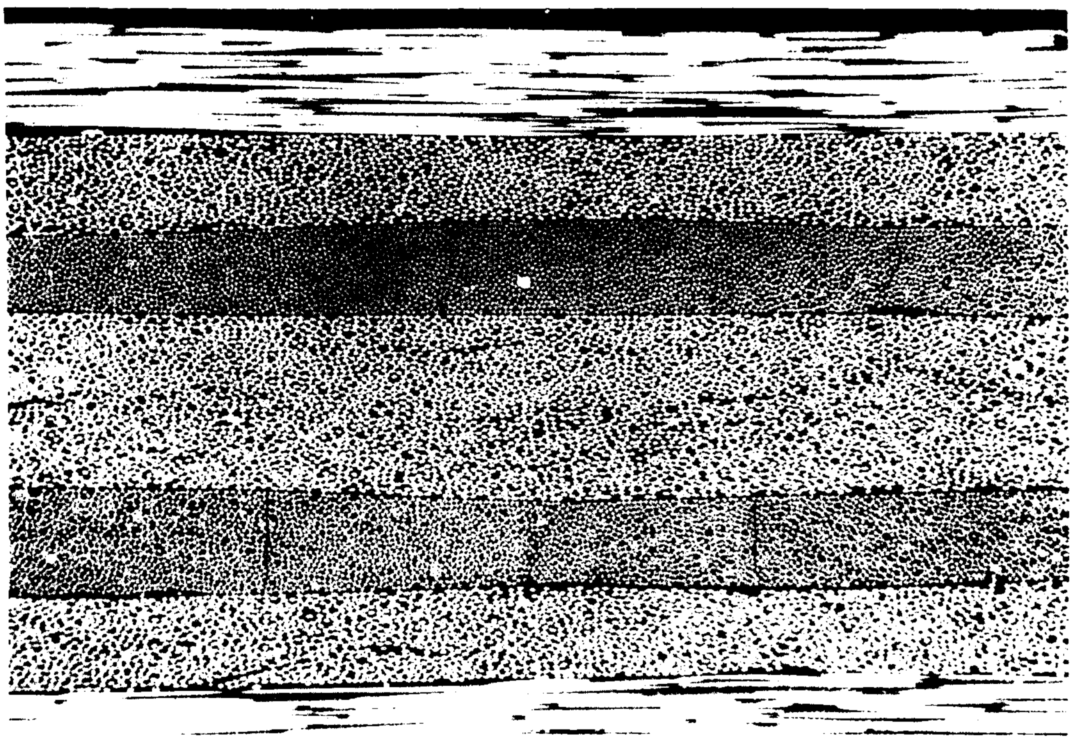

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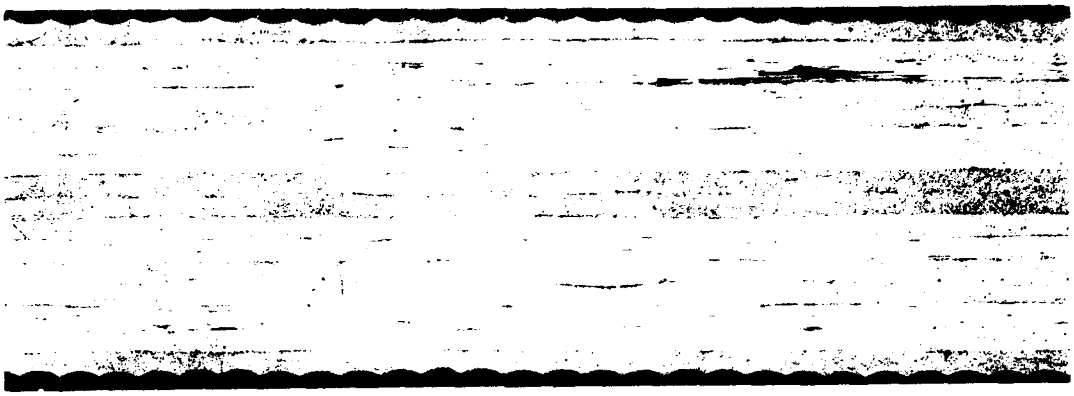
Figure D-5. - Longitudinal sections of area 1 of wet quasi-isotropic LlL specimen 2SY1424-55B loaded to 80% of σ_{TU}.



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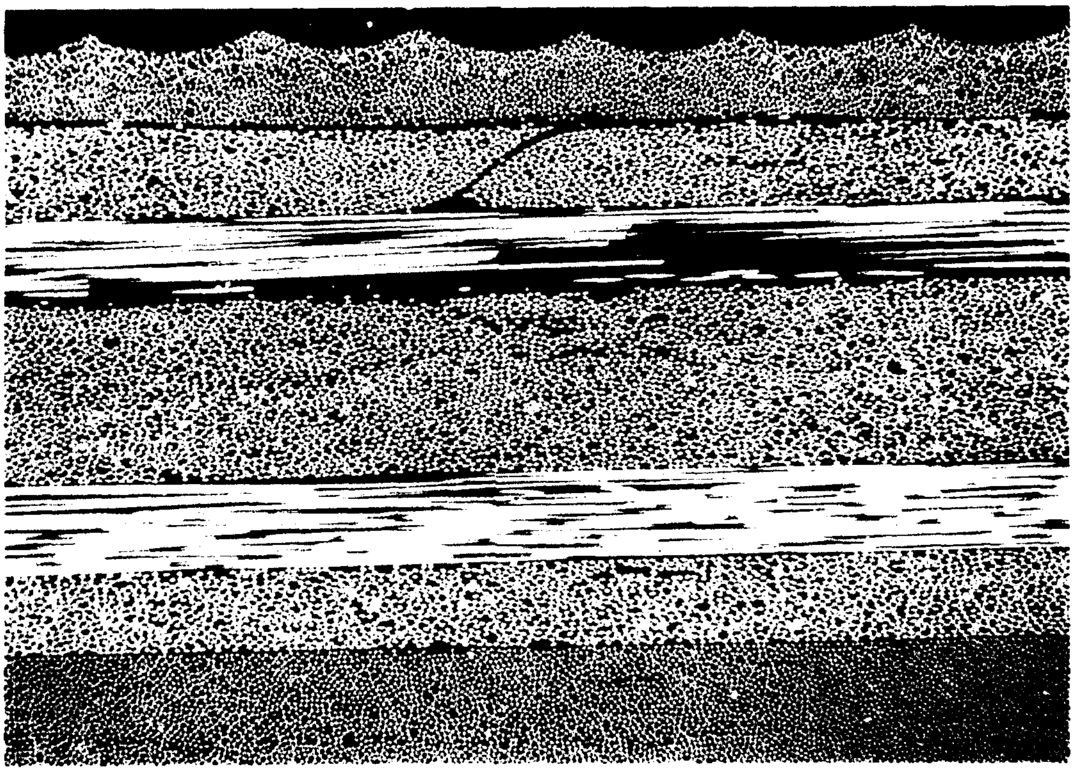

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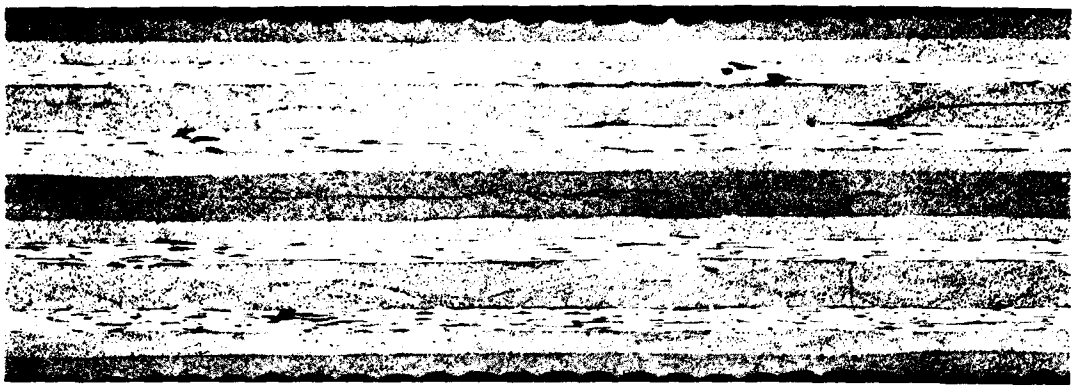
Figure D-6. - Transverse sections of area 4 of wet quasi-isotropic LlL specimen 2SY1424-55B loaded to 80% of σ_{TU} (section taken through crack).



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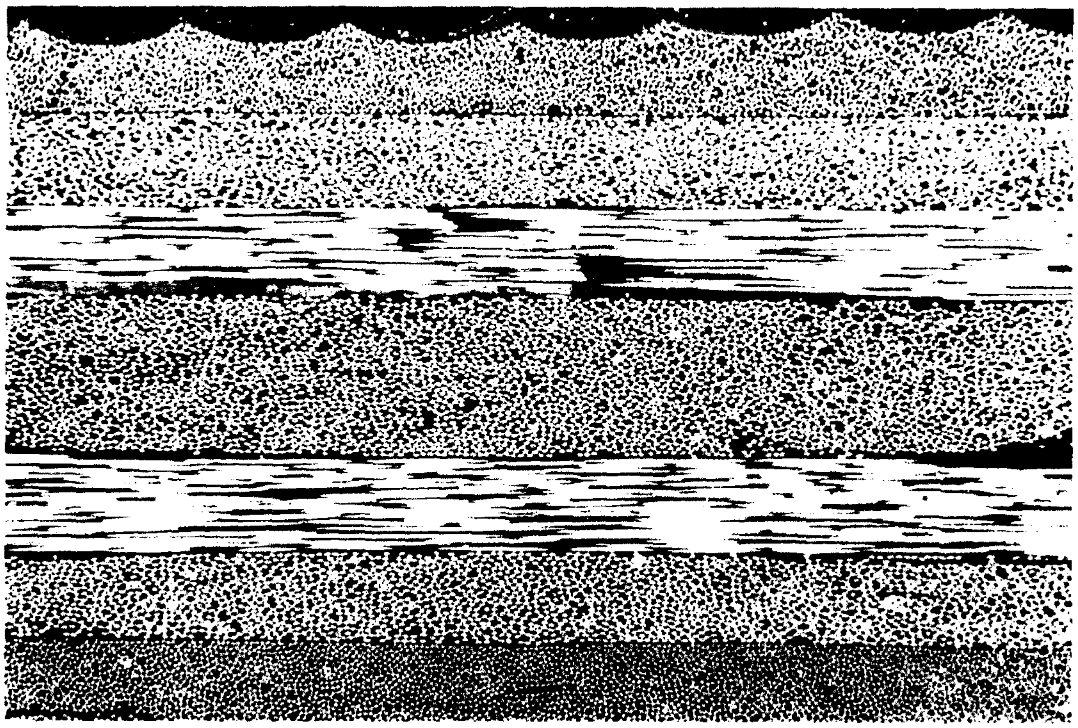

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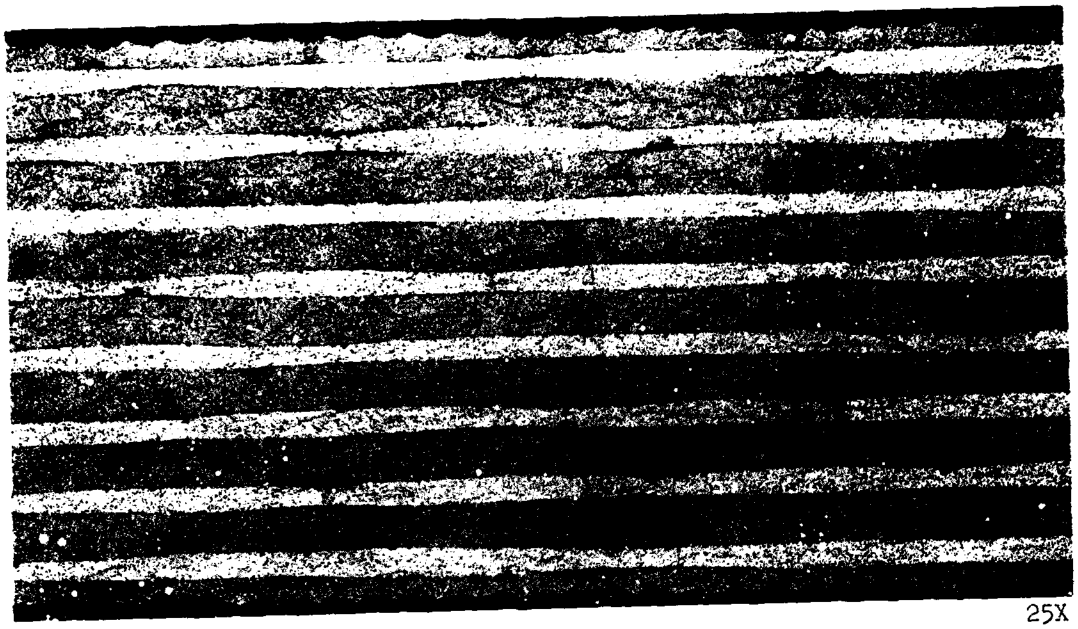
Figure D-7. - Transverse sections of area 5 of wet quasi-isotropic L1L specimen 2SY1424-55B loaded to 80% of σ_{TU} (sections taken through cracks).



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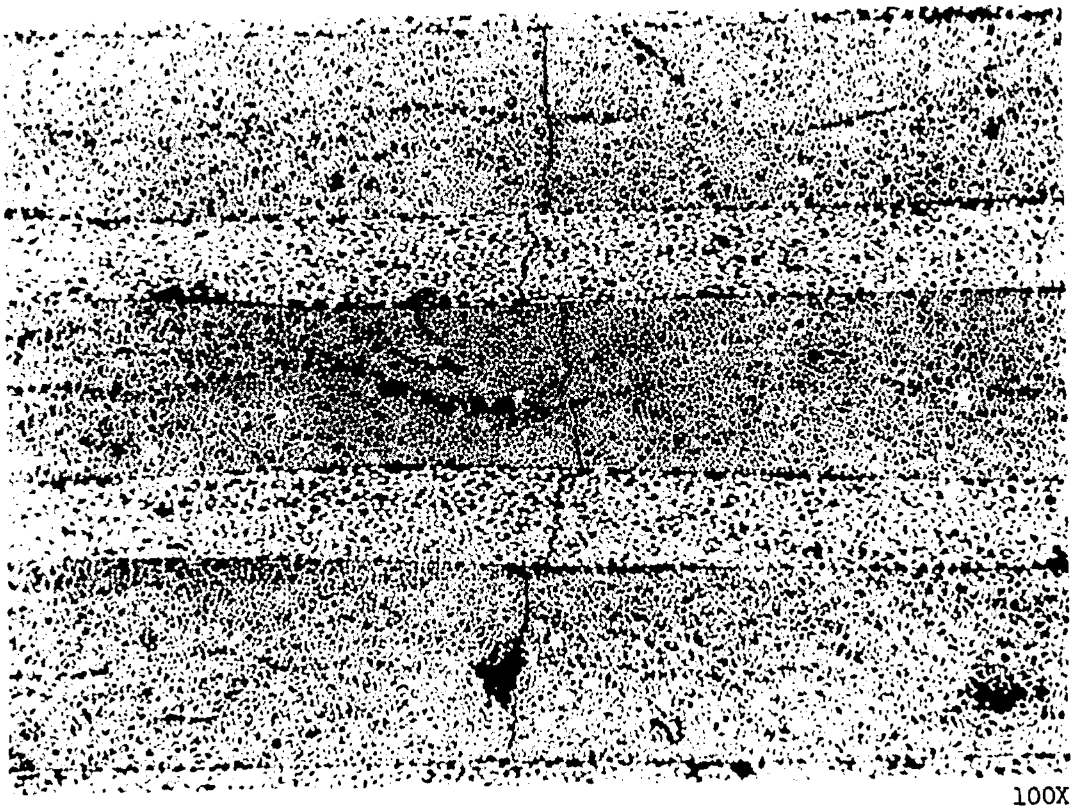
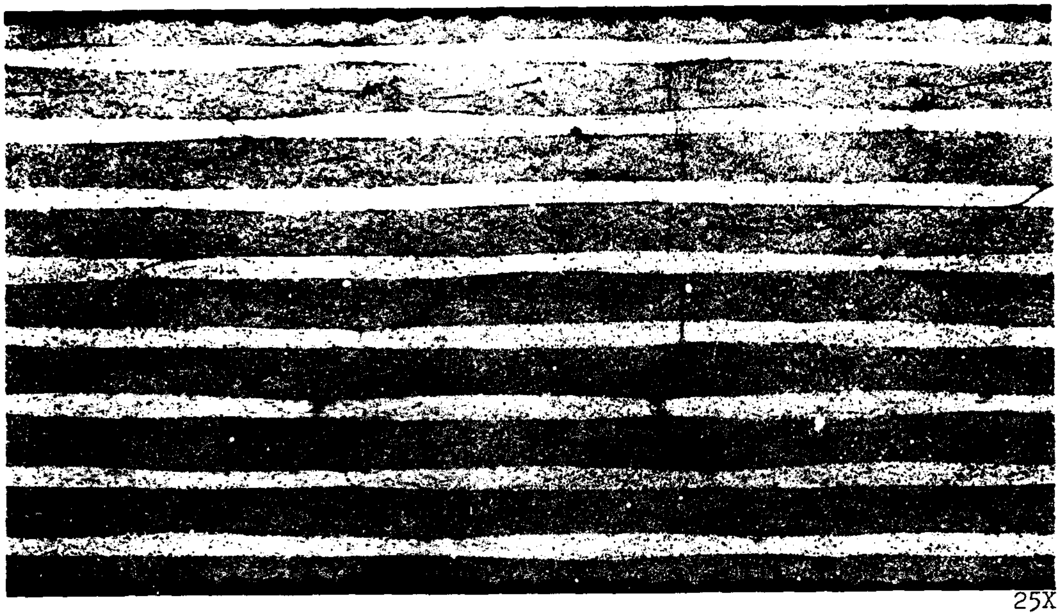
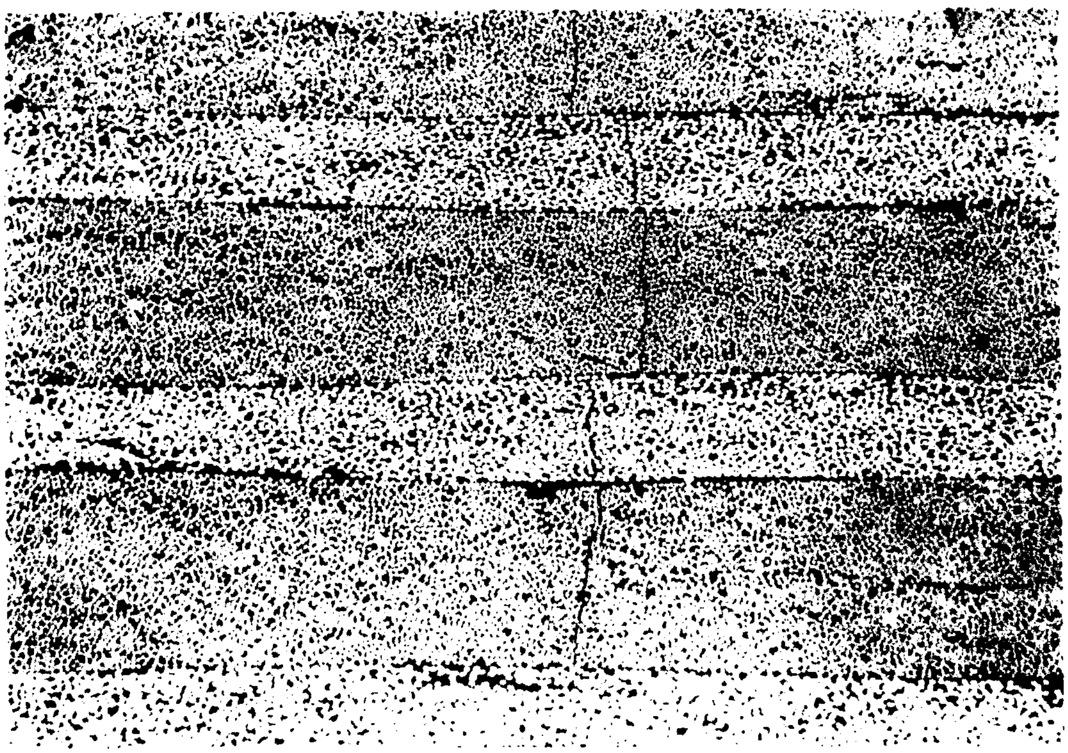


100X

Figure D-8. - Longitudinal sections of area 1 of dry 67% - 90°, 33% ±45° L2T laminate specimen 1SY1423-9C loaded to 80% of σ_{TU}.

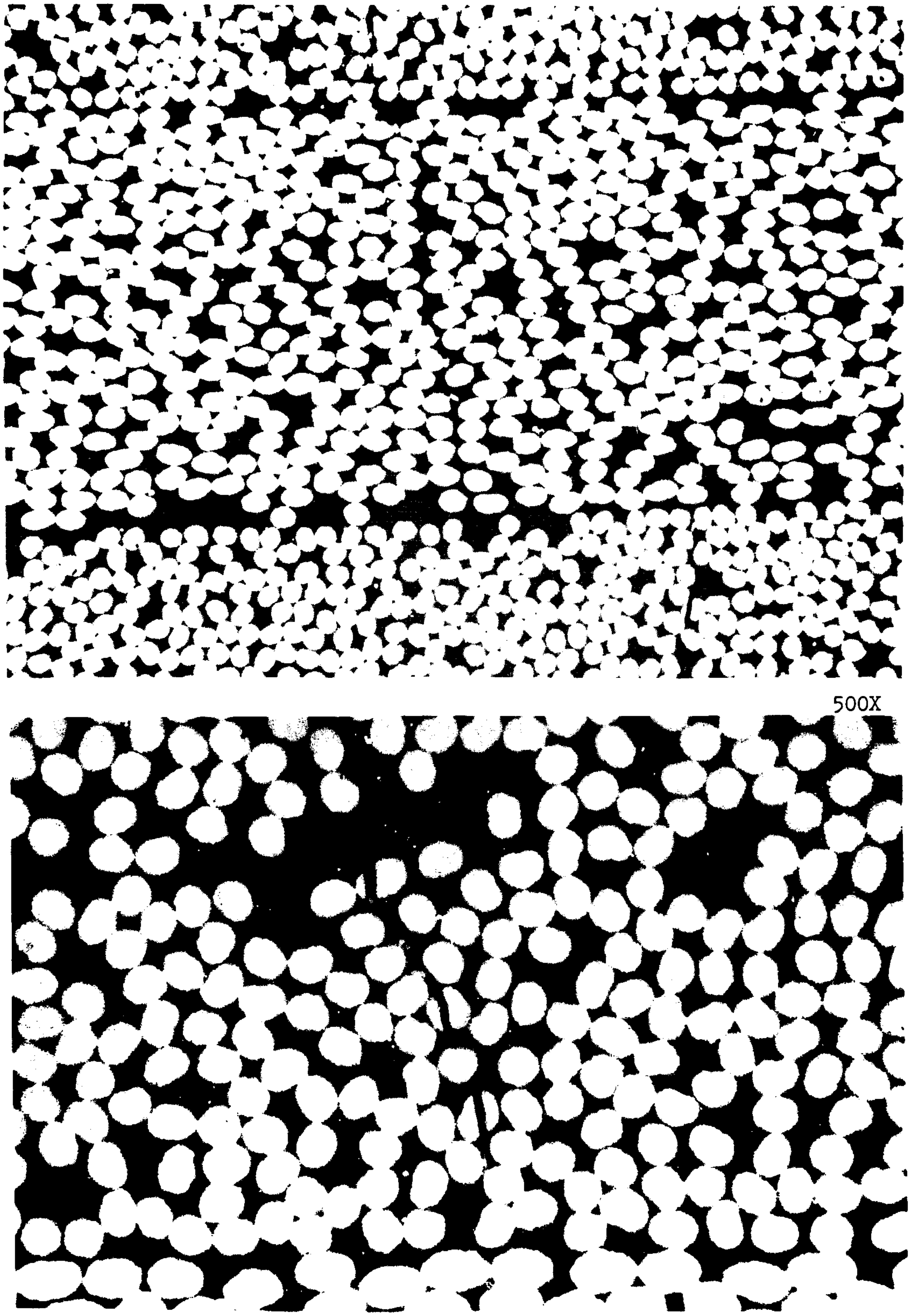


25X



100X

Figure D-9. - Longitudinal sections of area 4 of dry 67% - 90°, 33% ±45° L2T laminate specimen 1SY1423-9C loaded to 80% of σ_{TU}.



500X

1000X

Figure D-10. - Longitudinal sections of area 4 of dry 67% - 90°, 33% $\pm 45^{\circ}$ L2T laminate specimen 1SY1423-9C loaded to 80% of σ_{TU}.

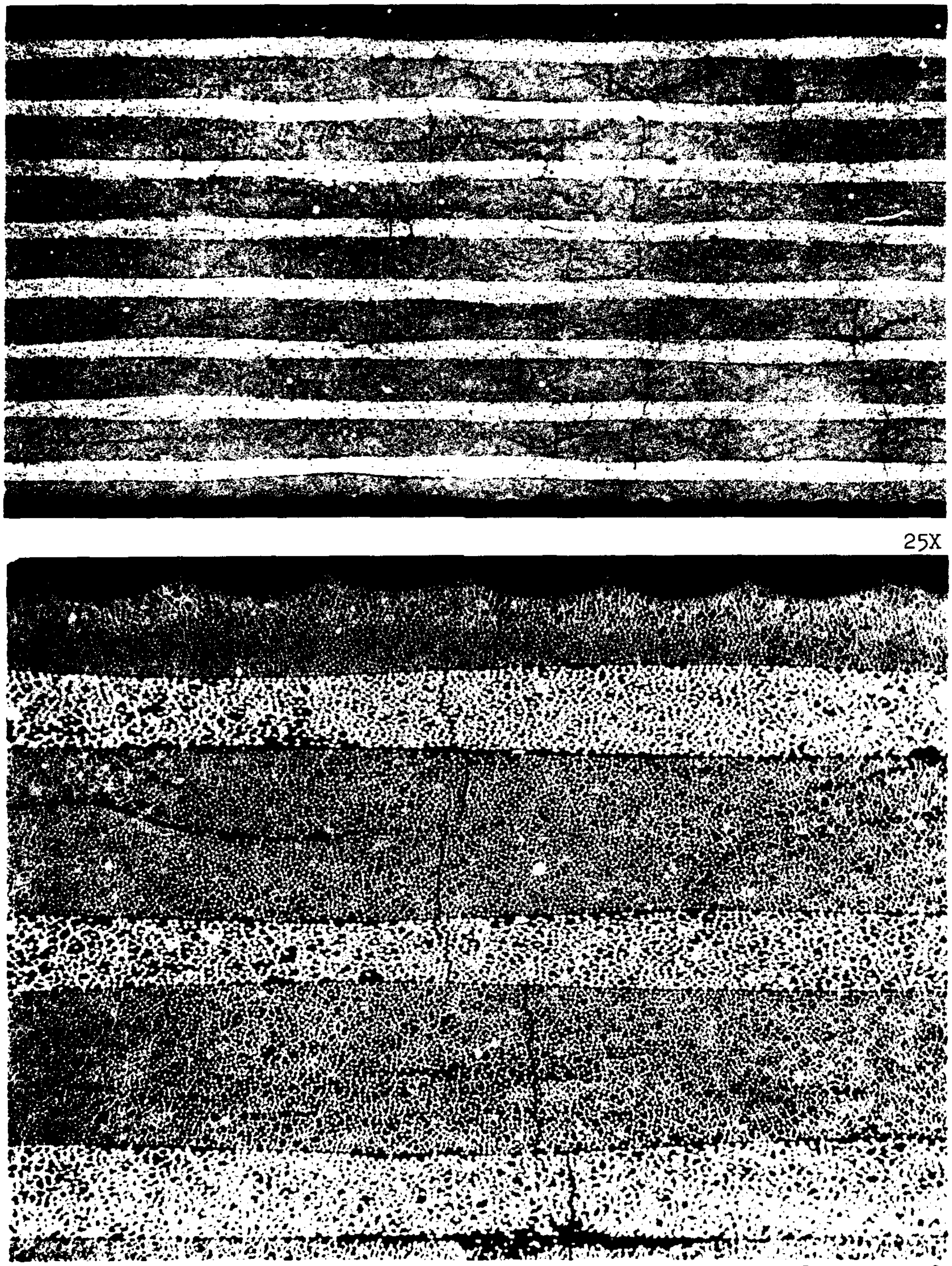


Figure D-11. - Longitudinal sections of area 4 of wet 67% - 90°, 33% ±45° L2T laminate specimen 2SY1423-20C loaded to 80% of σ_{TU}.

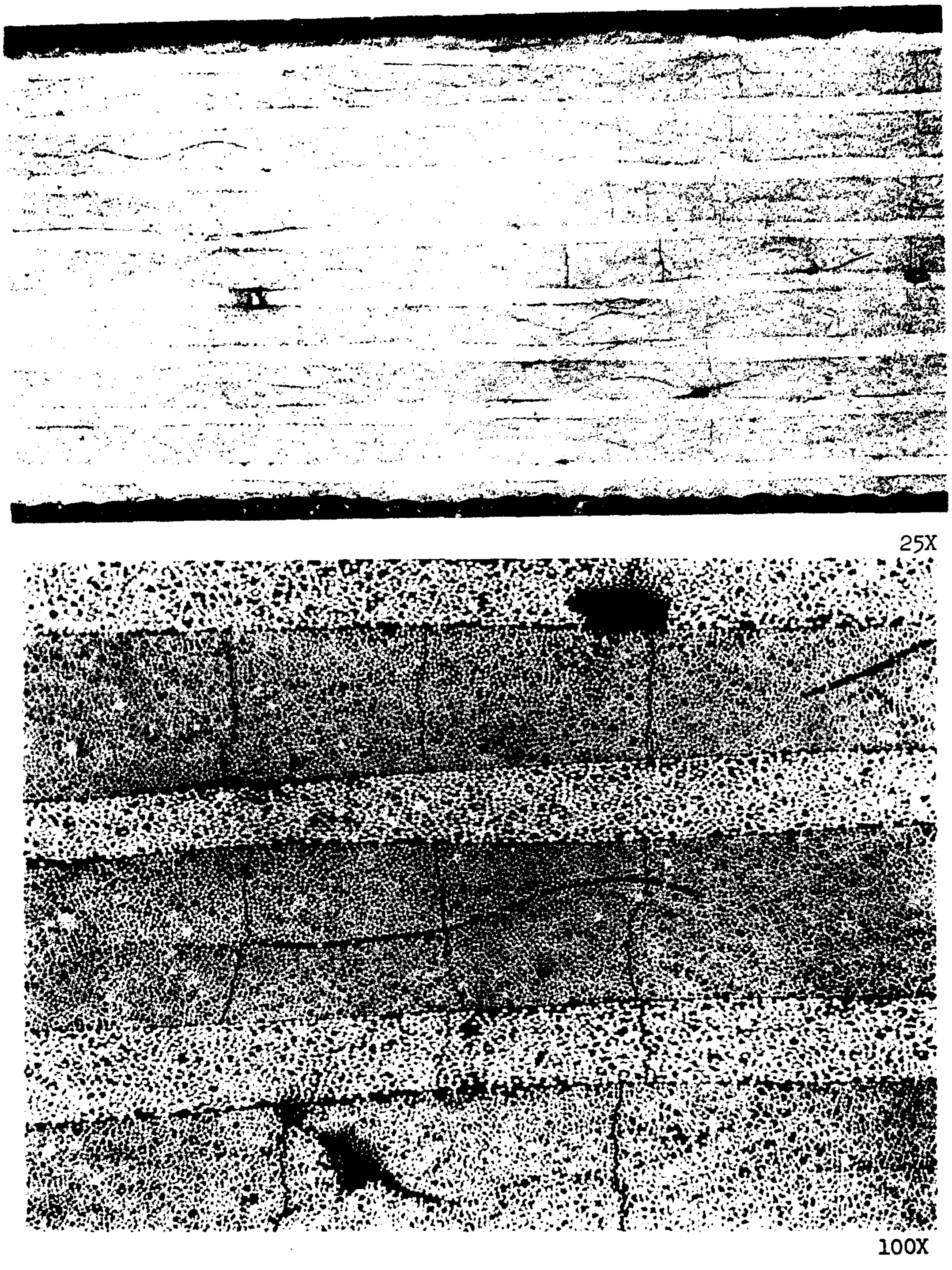
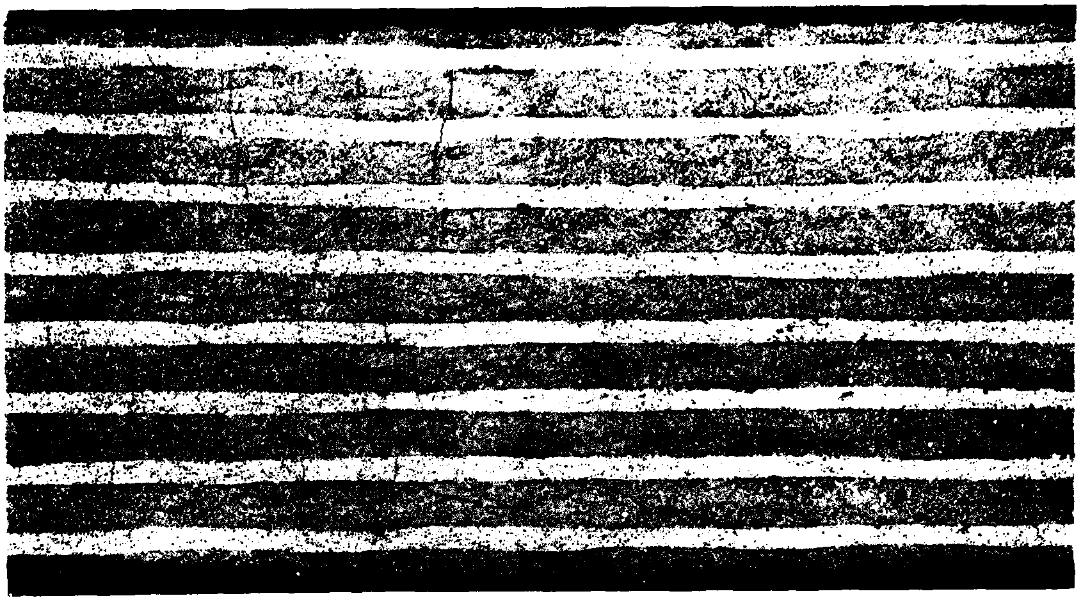


Figure D-12. - Longitudinal sections of area 6 of wet 67% - 90°, 33% +45° L2T laminate specimen 2SY1423-20C loaded to 80% of σ_{TU}.



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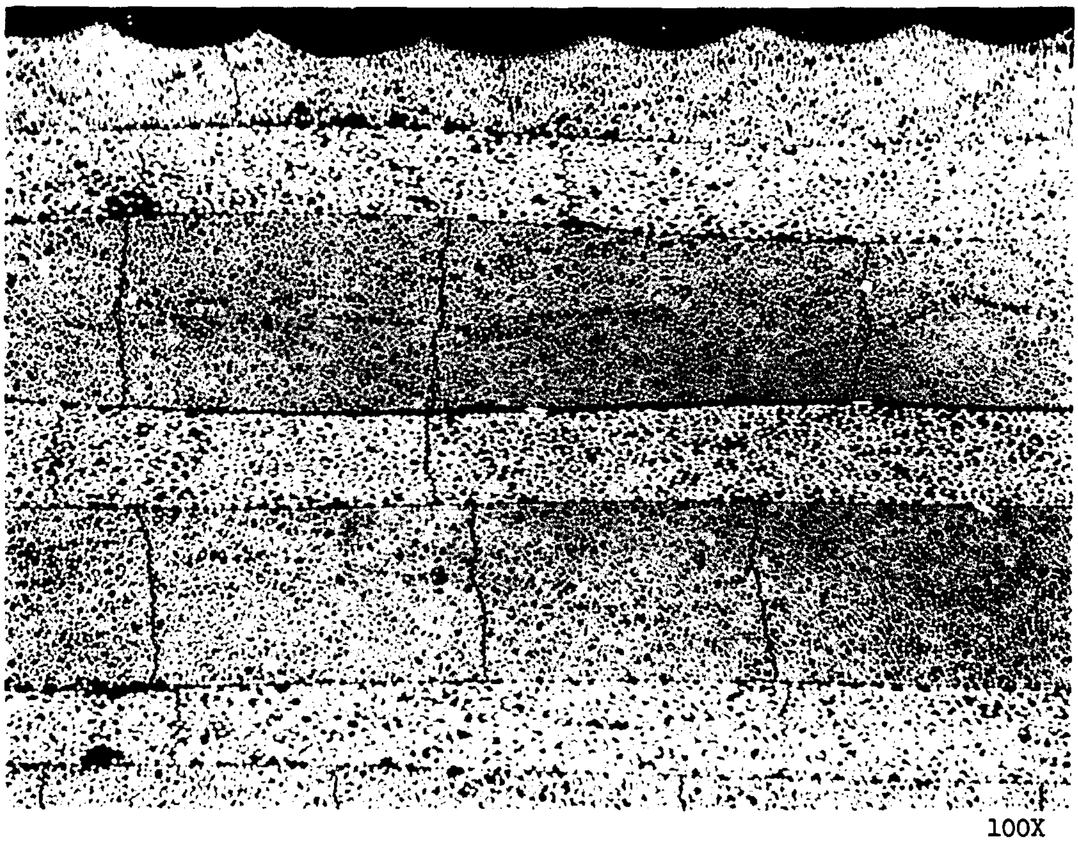

100X

Figure D-13. - Longitudinal sections of area 4 of wet 67% - 90°, 33% $\pm$45° L2T laminate specimen 2SY1423-20C loaded to 80% of σ_{TU}.

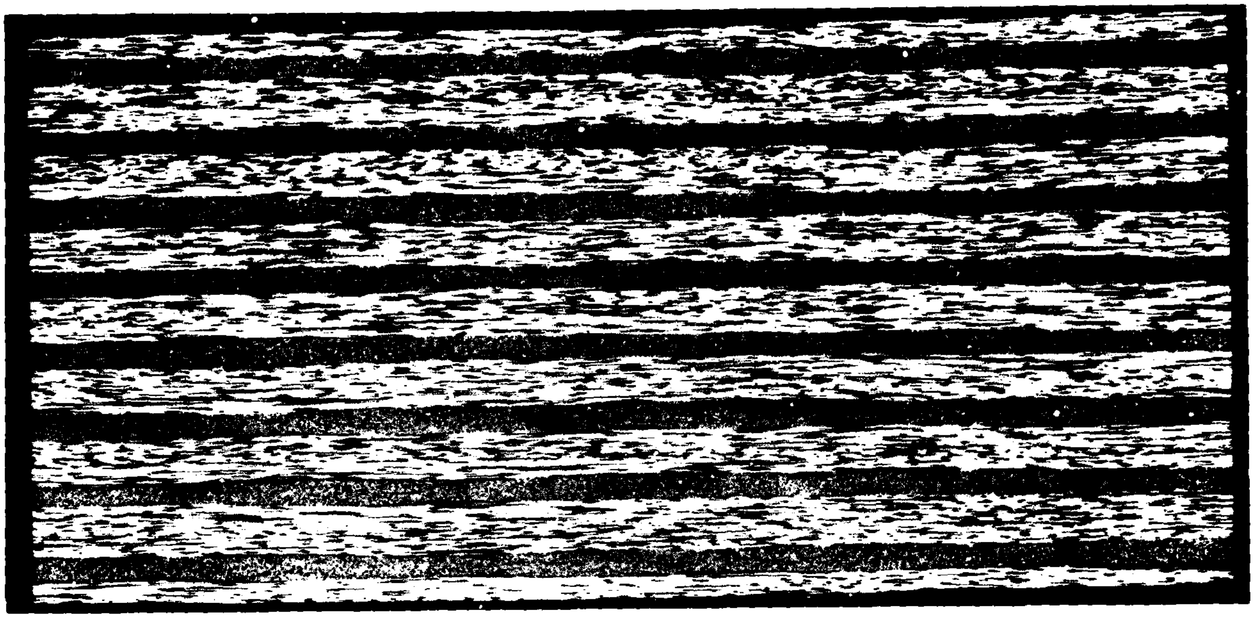

Figure D-14. - Longitudinal section of area 1 of wet 67% - 0°, 33% $\pm 45°$ L2L laminate specimens 2SY1423-23A loaded to 90% of σ_{TU} - no cracking evident.

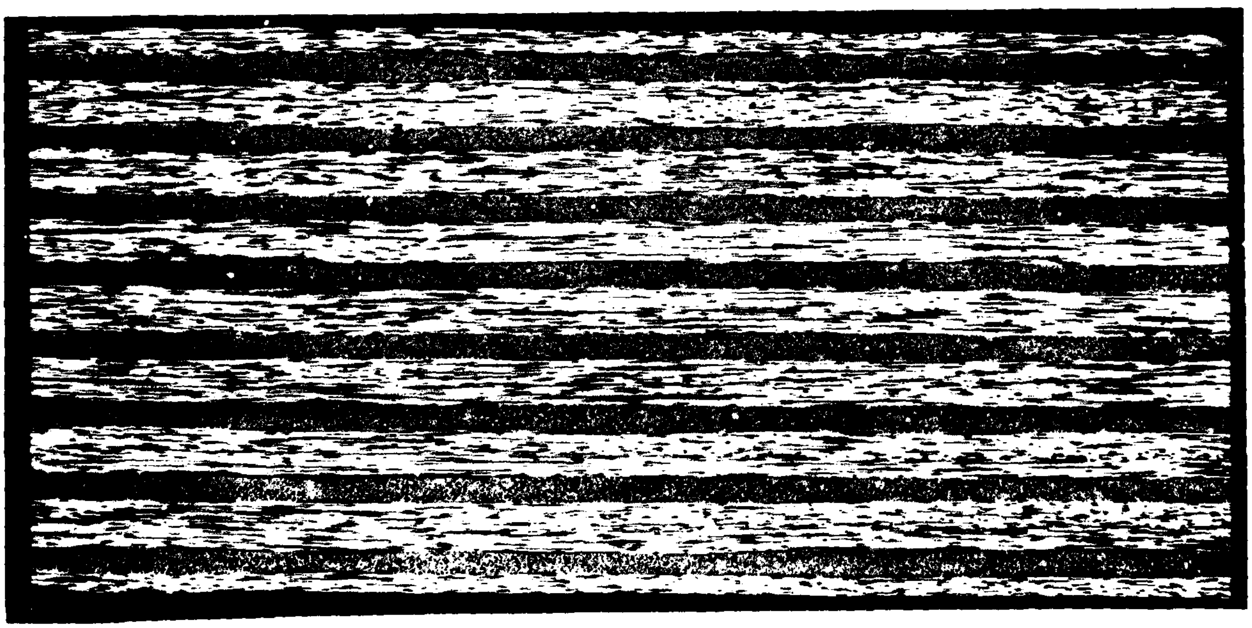

Figure D-15. - Longitudinal section of area 1 of wet 67% - 0°, 33% $\pm 45°$ L2L laminate specimens 2SY1423-23A loaded to 90% of σ_{TU} - no cracking evident.

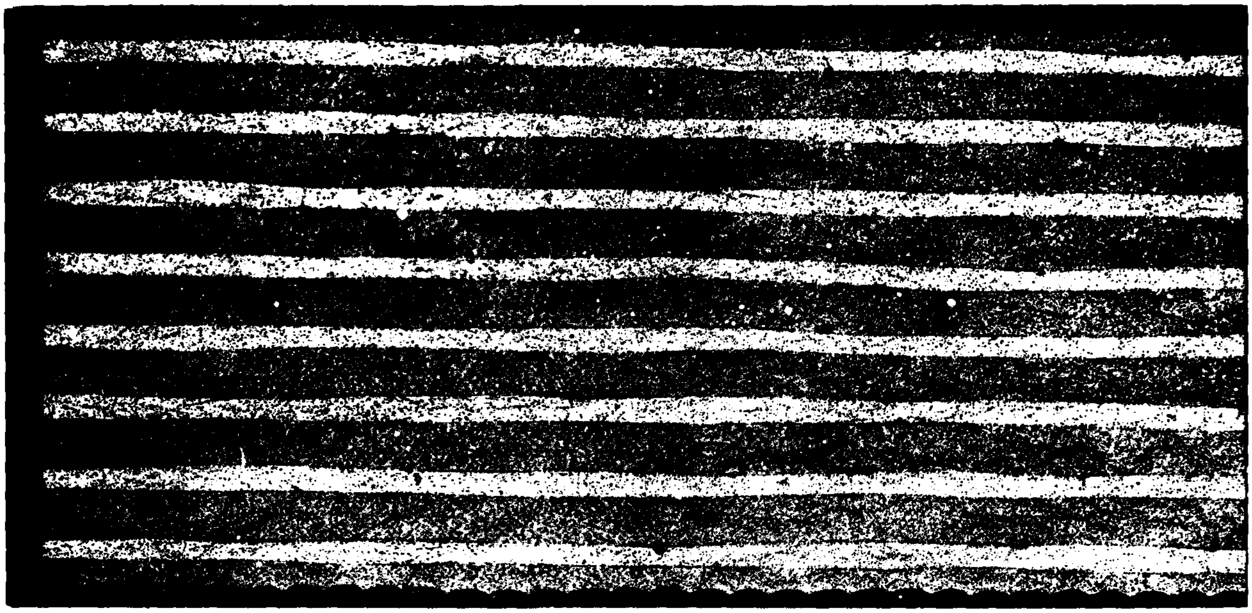

Figure D-16. - Transverse section of area 4 of wet 67% - 0°, 33% ±45° L2L laminate specimen 2SY1423-23A loaded to 90% of σ_{TU} - no cracking evident.

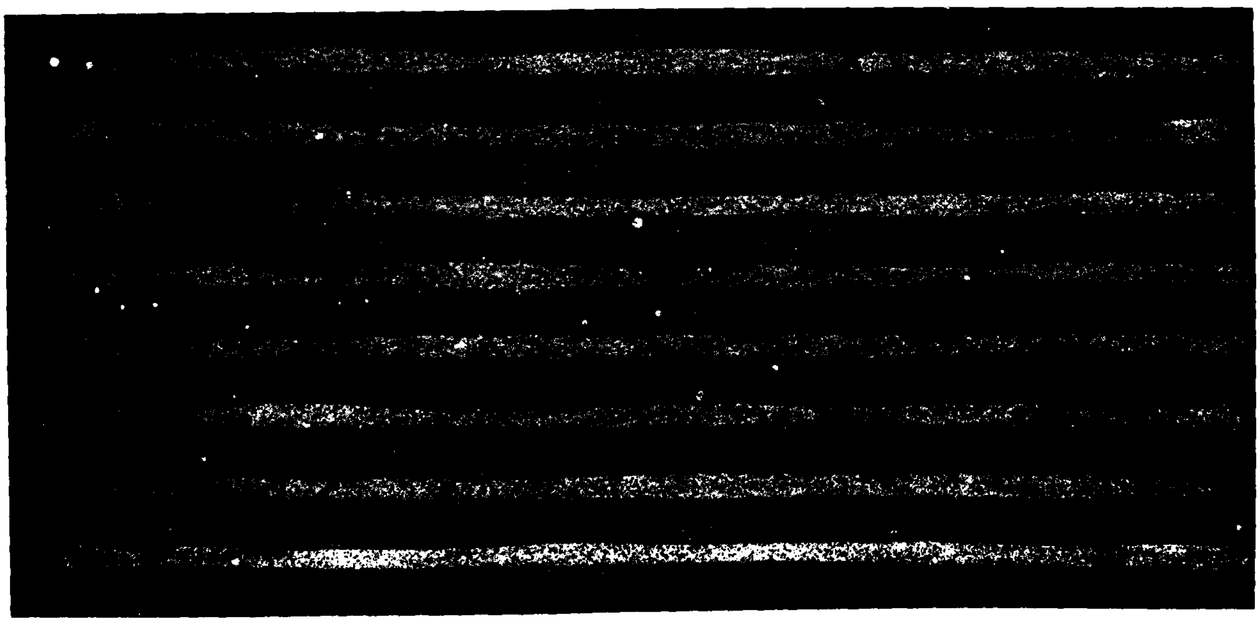

Figure D-17. - Transverse section of area 5 of wet 67% - 0°, 33% ±45° L2L laminate specimen 2SY1423-23A loaded to 90% of σ_{TU} - no cracking evident.

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